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Practical Electricity

AN ELECTRICAL CATECHISM

IN THREE VOLUMES

VOLUME III

OPERATION AND MANAGEMENT OF ELECTRIC MOTORS, LAMPS AND POWER STATIONS

BY

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DIRECT-CURRENT MOTORS

PRINCIPLES GOVERNING THEIR ACTION

788. What is a direct-current motor?

A direct-current motor is a machine for converting energy in the form of direct-current electricity into energy in the form of mechanical motion.

789. How does this conversion take place?

Through the force of two magnetic fields mutually exerted upon each other within a small space between the stationary and movable members of the electric motor.

790. Does it make any difference how the two magnetic fields are formed?

Only a difference in degree. The two magnetic fields may be formed by currents flowing in two wires (straight or coiled, with or without cores), or by two permanent magnets, or the one field may be produced by a current in a wire and the other field by a permanent magnet.

791. Explain how the magnetic fields produce mechanical motion in an electric motor.

When the lines of force of two magnetic fields meet without coinciding in direction, each set exerts a pull upon the other which tends to draw them into agreement as to their direction in space; this pull is transmitted to the parts in which the magnetic lines of force originate, and will tend to draw them into such a position that the lines of force of the two fields will coincide to the greatest possible extent. The greater the strengths of the magnetic fields, the stronger will be the force thus acting, and if the fields be sufficiently strong mechanical motion will be given to that part which moves the more readily.

792. Describe a simple arrangement which illustrates the magnetic action referred to in Answer 791.

Fig. 304 illustrates such an arrangement. One magnetic field is produced between the poles *N* and *S* of a horseshoe magnet, and the other by a current flowing in the loop of wire suspended between the magnet poles with its plane parallel to the lines of force of the magnet. The lines of magnetic force set up by the current will be projected at right angles to those of the magnet, which are represented by the light lines, and if the magnet be held so it cannot move and the loop be freely suspended, the latter will turn through

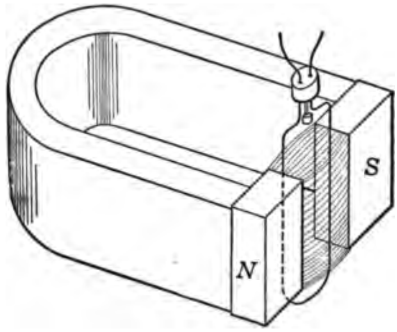

Fig. 304.—Loop Conductor in a Magnetic Field.

90 degrees to the position in which the lines of force of the magnet's field will thread through it in the same direction as its own lines. If the current through the loop be reversed in direction, the direction of the lines of force formed by it will be reversed, and the loop will tend to turn through 180 degrees or until the lines of force of both fields again coincide in direction.

793. How is magnetic action practically applied in an electric motor?

Suppose an armature with one coil connected to a two-bar commutator, as shown in Fig. 305, be placed in a magnetic field between the poles *N* and *S*. If brushes be pressed against the commutator *1-2*, as indicated in the sketch, and a current

be sent through the coil in the direction indicated by the small arrowheads, this current will set up a magnetic field in the armature core *a* and the surrounding air, and the lines of magnetic force will have the direction of the arrow *A* through the core. The lines of force set up by the magnet have the direction shown by the arrows near the letters *N* and *S*, and the magnetic pull between these two fields will turn the armature over in a clockwise direction until the arrow *A* is parallel with the arrows on the magnet poles, as shown by Fig. 306. When this position is reached, the pull between the two magnetic fields ceases, because their lines of force coincide,

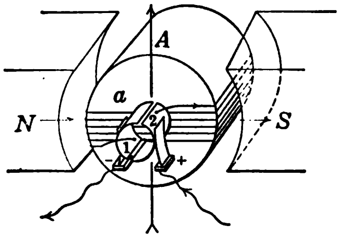

Fig. 305.—Position of Maximum Magnetic Pull.

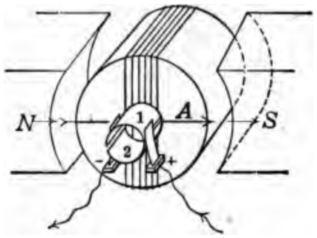

Fig. 306.—Position of Minimum Magnetic Pull.

and the armature would come to a stop in this position, so far as the pulling force is concerned, but for the commutator.

794. How does the commutator keep the armature revolving?

When the armature reaches the position shown in Fig. 306, its momentum carries it slightly past, so that the positive brush touches the half *1* of the commutator and the negative brush touches the half *2;* this reverses the current through the coil and the magnetic field set up by it is also reversed. Consequently, instead of agreeing with the main field set up by the magnet, the armature field is in opposition to it and the two react to pull the armature around in the same direction as before, one-half a revolution, to the position opposite that in Fig. 306. When the momentum of the armature car-

ries it past this position, the brushes and commutator again reverse the direction of the current in the armature coil, and the armature is kept revolving.

795. Has a motor armature only one coil?

No; it has a number of coils, connected up to a commutator with a number of divisions, and as each coil passes the position midway between the magnet poles, the current flowing through it is reversed, as described for the single coil.

796. What determines the speed of rotation of the armature of a motor?

The counter electromotive force developed in the coils of the armature.

797. What is the counter electromotive force?

It is the electromotive force induced in the armature conductors by their cutting the lines of force of the field set up by the magnet, as in a dynamo.

798. What determines the strength of the counter electromotive force of a motor armature?

The speed or rapidity with which the armature conductors cut across the magnetic field, the strength of that field and the number of conductors connected in series in the armature winding.

799. What is the direction of the counter electromotive force with respect to the armature current?

The counter electromotive force induced in each conductor by its motion through the main magnetic field is always in opposition to the current in the conductor which produces that motion.

800. How does the counter electromotive force affect the speed of rotation of an armature?

It tends to stop the motion of the armature because it opposes and decreases the current which is flowing through the coils of the armature, and the motion of the armature due to that current varies proportionally with the strength of the current.

801. Can counter electromotive force be measured directly?

No, but it can be calculated for any load on the armature by subtracting the voltage drop in the armature circuit at that load from the voltage applied to the brushes of the motor in order to run it.

802. How is the voltage drop ascertained?

By multiplying the resistance of the armature circuit (measured between brushes) by the current which flows at the load under consideration.

803. What relation exists between the armature speed of a motor and the armature current?

The current varies inversely to variations in the speed, when the motor is supplied from a constant-potential circuit. That is, when the speed increases, the current immediately drops in value. If the difference between the applied and counter electromotive forces be divided by the resistance of the armature circuit, the result will be the current passing through the armature.

804. Does not a motor take a very large current in comparison with its normal running value, in starting from rest?

It does, because the internal resistance of the armature is very small and the counter electromotive force at standstill is zero. If this current were maintained for any considerable length of time it would damage the armature, but as soon as the armature begins to move the current diminishes, until in a very short time the speed of rotation and, consequently, the counter electromotive force become sufficiently high that only a small current can flow through the armature.

805. Does not this decrease of current lessen the force tending to cause the armature to revolve?

It does, and early inventors tried to get rid of counter electromotive force because it limited the amount of current that passed through the armature, but their ideas were soon proved to be wrong.

806. Have the lines of force developed by the current in the armature coils of a motor any effect upon the direction of lines of force produced by the field magnet?

Yes, a distortion of the magnetic flux occurs, somewhat as shown in Fig. 307. The amount of distortion depends, as in the case of a generator, on the relative strengths and the relative directions of the magnetic fields developed by the armature and the field magnet. A very slight distortion occurs when the magnetic strength of the field is strong in comparison with that of the armature.

In order to prevent sparking at the brushes it is necessary, as in the case of a generator, to set the brushes along a line

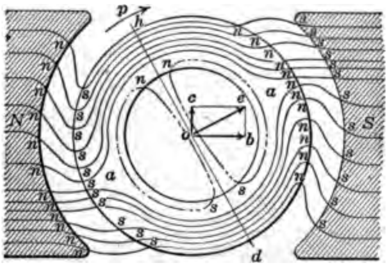

Fig. 307.—Distortion of Magnetic Field in a Motor.

practically at right angles to the resultant lines of force. The direction of the resultant lines of force of a motor is such, in most cases, that the brushes must be shifted backward, or opposite to the direction of rotation of the armature, in order to obtain sparkless commutation.

807. Explain more fully the effect of the distortion of the field of a motor upon the position of the brushes.

Referring to Fig. 307, *a a* represents the iron core of an armature rotating in the direction of the arrow *p* between the field magnet poles *N* and *S*. Assuming the direction and intensity of the lines of force of the field magnet alone to be represented by the direction and length of the line *o b*, and the direction and intensity of the lines of force of the armature by the direction and length of the line *o c*, the

diagonal or resultant *o e* of the rectangle thus formed represents by its direction and length the direction and strength of the resultant field.

The resultant lines of force *n s, n s,* etc., pass through the core of the armature in the direction indicated by the diagonal line *o e,* and the brushes, to be set on a line at right angles to the resultant field, must be placed on the line *h d.*

808. Do the magnetic lines of force heat the field magnet?

Not directly, but if the poles are not laminated, eddy currents will be generated by the lines of force at those parts where the field is of greatest density, and these will tend to heat the pole tips which are diametrically opposite to each other.

809. Does the resultant field of a motor change its direction sufficiently during operation to necessitate a change in the position of the brushes?

If the load on a motor fluctuates widely, the current through the armature will vary considerably, and the resultant field will change in direction. This may require a movement of the brushes to prevent sparking, but if the strength of the field produced by the magnets be made very powerful in comparison with that produced by the armature, the resultant field will change so little that no sparking will result from the usual variation in the armature current due to fluctuating loads and the position of the brushes will not have to be changed.

810. Is there any disadvantage in using very powerful field magnets?

If the magnets be made very powerful, the weight of the motor will be much greater than if a weaker magnet were used, but the advantages gained by the use of a powerful field magnet more than offset the expense of the extra weight.

811. Do hysteresis and eddy currents in the magnet poles affect the resultant magnetic field of a motor?

Yes; they shift it slightly in the direction of rotation, so

that the brushes require less shifting from the exact mid-pole position in order to prevent sparking than if there were no hysteresis or eddy currents.

812. Explain why the brushes of a motor should ordinarily be set along a line at right angles to the resultant magnetic field to prevent sparking.

Refer, for example, to the armature coil *s*, in Fig. 308, which is rising on the left while the armature is rotating in the direction of the arrow *p*. Current is passing through the coil *s* from the brush *b* as indicated by the other arrows. At the same time, the coil *s* has induced in it a counter electro-

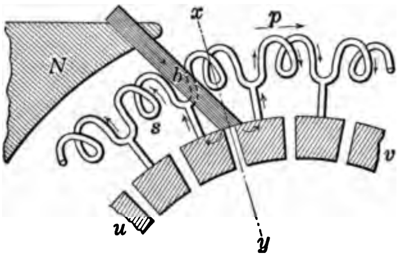

Fig. 308.—Illustrating Commutation in a Motor.

motive force which opposes the flow of this current. In order to prevent sparking between the brush and the commutator when the bar connected to the coil *s* passes under the brush and the short-circuit of the coil is broken, this action must occur when the coil is carrying a minimum current; it must therefore occur when the coil is moving in a field which will be just strong enough to reverse the direction of the current in the coil without changing its value appreciably. If the bars connected to the coil pass under the brush when the coil is just leaving the magnetic field, as from the tip of the pole *N* in the diagram, this condition will be sufficiently well obtained and there will be little, if any, tendency to spark.

813. How is the pull between the field magnet and the

armature, which causes the armature of a motor to revolve, measured?

This pull, which is called the torque (pronounced "tork") of the motor, is measured in foot-pounds. It is the product of the radius of the armature by the magnetic pull at its circumference, the radius of the armature being measured in feet and the pull at the circumference of the armature in pounds.

814. What is the formula for calculating the torque of a motor?

Let HP = Horse-power which the motor is developing,
S = Speed of the armature in revolutions per minute,
T = Torque in pounds at a radius of 1 foot, or the foot-pounds,

Then

$$T = \frac{5252 \times HP}{S}.$$

815. What is the torque exerted on the armature of a motor developing 50 horse-power, if its speed be 600 revolutions per minute?

Substituting the known values of HP and S in the formula in Answer 814, the result is as follows:

$$T = \frac{5252 \times 50}{600} = 437.7 \text{ foot-pounds.}$$

816. How is the horse-power of a motor calculated when its speed and torque are known?

By transposing the formula in Answer 814 as follows:

$$HP = \frac{S \times T}{5252},$$

and using this transposition.

817. Show the application of this formula to a motor running at 300 revolutions per minute and exerting a torque of 750 pound-feet.

Substituting the respective values of $S = 300$ and $T = 750$ in the formula in Answer 816, the result is

$$HP = \frac{300 \times 750}{5252} = 42.8 \text{ horse-power.}$$

818. What is the formula for calculating the speed of a motor when the horse-power and torque are known?

Another transposition of the formula in Answer 814, thus:

$$S = \frac{5252 \times HP}{T}.$$

819. Illustrate the application of the formula in Answer 818, assuming a motor gives 10 horse-power with a torque of 100 foot-pounds.

$$S = \frac{5252 \times 10}{100} = 525.2 \text{ revolutions per minute.}$$

820. What relation exists between the torque and the current?

Since the horse-power is proportional to the product of the voltage and current for which the motor is designed, and as the voltage is proportional to the speed, if volts × amperes be substituted for horse-power and volts for speed, with the proper multipliers, the resulting formula will show that the torque in any particular motor is always the same for a certain value of the current, whatever the speed may be.

821. Explain Answer 820 more fully.

One horse-power is equal to 746 watts; therefore, volts × amperes ÷ 746 = horse-power, or

$$HP = \frac{E \times I}{746}.$$

The voltage E is equal to the revolutions per minute × field strength × number of armature conductors ÷ a number depending on the type of winding used, or by the use of symbols in the order given,

$$E = \frac{S \times \Phi \times w}{K}.$$

Therefore, by transposition,

$$S = \frac{E \times K}{\Phi \times w}.$$

Dividing both sides of the equation $HP = \frac{E \times I}{746}$ by S and on the right side substituting for S the value just found,

$$\frac{HP}{S} = \frac{E \times I \times \Phi \times w}{746 \times E \times K}.$$

Canceling out the two E's,

$$\frac{HP}{S} = \frac{I \times \Phi \times w}{746 \times K}.$$

Now the field strength Φ, the number of wires w and the number K all remain fixed in an ordinary motor, so that

$$\frac{HP}{S} \text{ is proportional to } I,$$

and as the torque varies exactly with $\frac{HP}{S}$, it also varies directly with the armature current I, and is not affected by the speed alone.

822. Mention some of the factors which limit the horse-power at which a direct-current motor can be rated.

The speed of rotation, sparking at the commutator, and the heating of the parts; in other words, the power of a motor to keep up to normal speed, to commutate well and to remain sufficiently cool in operation. ϕ ϕ

CONSTANT-POTENTIAL MOTORS

823. Are electric motors always supplied with power from a constant-potential source?

No, electric power may be supplied to a motor either at a constant voltage or at a constant-current value.

824. How does the regulation of speed compare in the two cases?

With a constant-voltage supply, good regulation is comparatively easy to obtain, while with a constant-current supply a special regulator must be provided to prevent the speed from becoming excessive at light loads, as explained in Answer 850.

825. Do constant-potential motors have shunt-wound or series-wound fields?

There are constant-potential shunt-wound motors, constant-potential series-wound motors and constant-potential compound-wound motors, but the first mentioned are in most common use.

826. Are the armature and field currents constant in a constant-potential shunt-wound motor?

If a constant voltage be maintained at the terminals of the motor, the current through the field-magnet coils will be constant after the coils have warmed up. The current through the armature, however, will vary in strength according to the load, its value being determined by the torque required to overcome the backward pull of the load.

827. Are the armature and field currents constant in a constant-potential series-wound motor?

No. The armature current of a series-wound motor varies according to the load requirements, and as the field winding is in series with the armature, the current in that winding is the same as the current in the armature winding and therefore varies.

828. Does the current in a series-wound motor vary as much as that in a shunt-wound motor armature?

Not with the same change in load. When the current in a series-wound motor increases, it strengthens the field and thereby increases the torque in addition to the increase due to the larger armature current. Therefore, a given increase in load demands less increase in current than in the armature of a shunt-wound motor, the latter having a constant field strength. The series motor is thus, to a certain extent, automatically controlled according to the requirements, making it very nearly self-regulating as regards current.

829. Is a shunt-wound motor self-regulating as regards current?

It is self-regulating, but it does not vary the armature cur-

rent exactly in proportion to load changes, because the armature current exerts a demagnetizing effect on the field magnet which weakens the field slightly when the armature current increases, and this decreases the torque. Consequently, the armature current must increase in slightly greater proportion than the increase in load.

830. Does the speed of a shunt-wound motor vary greatly, when current is supplied at constant voltage?

No; the smallest motors vary as much as 10 per cent. from no load to full load, but motors of moderate and large sizes vary only from 2 to 4 per cent.

831. Can such motors be made to operate at different speeds?

Yes; constant-potential motors are made to run at widely different speeds.

832. Describe the usual methods of regulating the speed of a shunt-wound motor.

Varying the field strength of a shunt motor is one of the most satisfactory ways of regulating its speed. Weakening the field strength reduces the counter electromotive force generated in the armature, and this tends to increase the speed of rotation. The field of a shunt-wound motor may be weakened by introducing resistance in its circuit, either by hand or automatically, or by altering the ampere-turns in any other manner, and this is one means employed to obtain various speeds from a given machine. Another method of changing the speed consists in changing the applied electromotive force by varying the resistance in the field of the generator supplying the power. This method, in general, can be used only when there is one motor supplied by the generator, for if there are others the speeds of all will be changed.

833. What effect upon the torque has the strengthening and weakening of a motor's field?

With a constant armature current, the torque of a motor would be increased by strengthening the field, for the torque

is proportional to the product of the armature current, the number of armature conductors and the strength of the field. The stronger field, however, would increase the counter electromotive force for the same speed, and this would reduce the armature current. Under ordinary conditions it is found that if the field of a motor on a constant-potential circuit be strengthened, there will result a more than proportional decrease of armature current. Consequently, within the limits of practical working, the torque of a motor is slightly increased by weakening the field.

834. What, in general, governs the direction of rotation of direct-current motors?

The relation between the direction of current flow in the armature conductors and the direction of the magnetic flux across the air gaps between the armature core and the field-magnet pole faces. With the field-magnet excitation unchanged, reversing the direction of the current through the armature will reverse the direction of rotation. If, instead of reversing the current in the armature circuit, the polarity of the field magnets be reversed and the current passed through the armature in the same direction as before, the rotation of the armature will be reversed.

835. Can direct-current generators be operated as motors?

They can, and in almost all cases without any radical change. With some special machines a slight change in the connection of the windings is necessary.

836. How will a series-wound generator behave if run as a motor?

If connected in circuit without any change in its own wiring, the armature will revolve in the opposite direction to that in which it would be driven as a generator.

837. What is the reason for the change in direction noted in Answer 836?

The counter-electromotive force developed in the armature

of a motor is always such as to oppose the flow of current through it. If the current passes through the windings of the machine in the same direction as when driven as a generator, the polarity of the field will remain the same, and the armature must therefore revolve in the opposite direction, running as a motor, in order that it may generate an electromotive force which will oppose the flow of current.

838. What will happen if the current be passed through the machine in the opposite direction to normal?

The armature will revolve in the opposite direction to that when run as a generator, because the polarity of the field will be reversed and the armature current is also reversed.

839. How can a series-wound generator be run as a motor in the same direction as when run as a generator?

By reversing the connections leading to either the field winding or the brushes, thereby reversing the relation between the polarity of the field and the flow of current in the armature winding.

840. How does a shunt-wound generator behave when run as a motor?

It will run in the same direction as when driven as a generator, because if the current passes through the armature in the same direction as before, it will be reversed in the field winding.

841. Suppose the current be passed through the armature in the opposite direction to that when running as a generator?

Then the polarity of the field magnet will be the same as when running as a generator, and in order that the counter electromotive force in the armature may oppose that applied, the direction of rotation must remain the same as before.

842. Why is the current through the shunt field winding reversed when the armature current remains unchanged, in changing from generator to motor?

Reference to Figs. 309 and 310 will make this clear. In

the former diagram the machine is represented as a generator, and the current leaving its positive brush divides, part going to the outer circuit and a small part through the shunt field winding in the direction indicated by the arrow *f*.

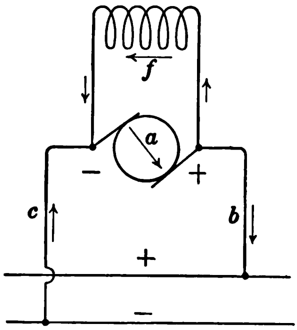

Fig. 309.—Direction of Current Flow in Shunt-Wound Machine operating as a Generator.

In Fig. 310 the machine is operating as a motor, and since the armature *receives* current from the line instead of *supplying* it, the leads *b* and *c* must be transposed in order to

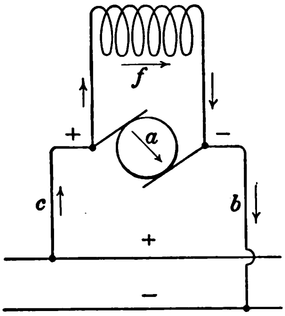

Fig. 310.—Direction of Current Flow in Shunt-Wound Machine operating as a Motor.

have the current go through the armature in the same direction as before. The current from the positive main wire follows the lead *c* to the brush and divides there, most of it going through the armature and a little through the shunt

field winding. The polarities of the brushes are reversed by the transposition of the leads *b* and *c*, and consequently the direction of flow through the field winding is reversed.

843. **As the current passes through the armature the same way in both generator and motor, why are the polarities of the brushes reversed?**

Because in the one case the brushes *deliver* power, and in the other they *receive* it. The positive terminal of any source of power is that from which the current passes outward; the

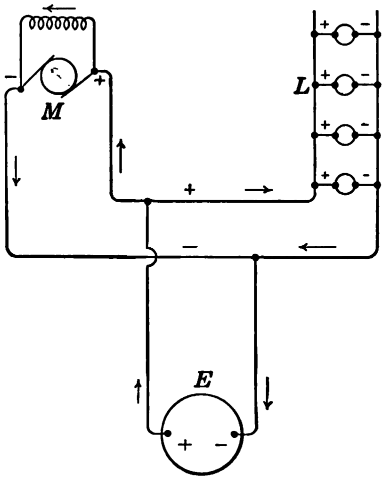

Fig. 311.—Diagram illustrating Relative Polarities of Supply and Receiving Apparatus.

positive terminal of any power-receiving circuit or apparatus is that at which current enters.

844. **Can the change in polarity of the brushes mentioned in 843 be shown by a diagram?**

Yes; Fig. 311 illustrates it clearly. Here *E* is any source of electricity, such as a generator or battery. To the line which it supplies are connected a motor *M* and a group of lamps *L*. Consideration of this diagram will make it clear that polarity is determined by the source of the current, the

"out-going" terminal being positive and the "entering" terminal negative.

845. What are the comparative advantages and disadvantages of series- and shunt-wound motors?

The field winding of a series-wound motor consists of a comparatively few turns of large wire; the field winding of a shunt-wound motor consists of a great many turns of small wire. Series-field coils are therefore easier to wind and less expensive to insulate than shunt coils, and the wire in the former costs less per pound; this construction is therefore less expensive. Series-wound motors are more easily started, especially under heavy loads. When supplied with current at constant potential, as in the case of electric-railway motors, the speed of a series-wound motor varies inversely as the load. Special provision is therefore necessary to control the speed.

Shunt-wound motors supplied with current at constant potential are very nearly self-regulating for variations of load. They may, therefore, be left largely to care for themselves between starts and stops, with only an occasional inspection of bearings and brushes. On the other hand, their speed cannot be varied through a very wide range without special construction or considerable loss, and they will not start under heavy loads as readily as series-wound motors. If the current supply to a shunt-wound motor be stopped, and the motor be left connected to the supply circuit, it is more liable to be burnt out when the current is restored than a series-wound motor would in starting itself automatically.

846. For what class of work is a series motor adapted?

It is suitable for work that requires a large starting torque and considerable variation in speed as in street cars, pumps, fans, etc., and where there is no danger of the load being removed or a belt slipping off; also where the potential of the supply circuit is subject to large and sudden changes. Some other applications are conveyor tables, where there is continuous heavy friction, reversing and intermittent; in crane hoists, for the trolley and bridge; draw bench, reversing; ore

unloaders; and in roll mills for the feed tables and screw down. They require constant attention for speed regulation, unless the load is constant or nearly so.

847. For what class of work is a shunt motor adapted?

It is adapted to work where there is a varying load that requires constant speed, as in a boring mill; for driving centrifugal blowers, centrifugal pumps, drill presses, hydraulic presses, lathes, pipe threaders, adjustable speed planers with shifting belt, reciprocating pumps, shapers and adjustable speed slotters; in fact, for driving most all kinds of machine tools and mill machinery. Shunt motors are self-regulating and may be left to operate without constant attention.

848. For what class of work is a compound motor adapted?

It is suitable for purposes requiring an increase of speed with decrease of load. Unlike the series motor, it will not race if unloaded, and is adapted for work where there are sudden heavy overloads, as in rolling mills for the feed tables: shunt and heavy series; centrifugal pumps and blowers: light series and shunt; conveyor tables (continuous light friction): shunt and light series; conveyor tables (continuous heavy friction): shunt and heavy series; draw bench (continuous chain): shunt and light series; draw bench (reversing): shunt and heavy series; pipe welding: shunt and light series; planer (constant speed): shunt and light series; reciprocating pump: light series and shunt; saw: shunt and light series; shear: shunt and heavy series; slotter (constant speed): shunt and light series; straightener: shunt and light series.

Unless constant speed is required, compound motors are especially adapted for handling fluctuating loads. The shunt winding keeps the speed within reasonable limits and prevents the motor from racing at no load; the series winding strengthens the field so as to give powerful torque without If the voltage and the load are constant, a compound motor will run at constant speed; and as such a motor will start

a given load with less current than is required by a shunt motor, compound motors can be used to advantage in many places for constant loads. If the voltage fluctuates, compound motors will run more steadily and give better results than shunt motors, as for example in operating stationary motors on street railway circuits.

CONSTANT-CURRENT MOTORS

849. How are constant-current motors used?

Very few are in use, because constant-potential motors are so much more satisfactory. Constant-current motors are usually series-wound and operated on an arc-light circuit, which is the only kind of constant-current circuit in this country. No starting rheostat is required, because the current through the motor cannot be greater at the start than when the motor is running regularly, the current throughout the whole circuit being kept constant by the generator.

850. What effect has the load of a constant-current motor upon its speed?

A series-wound constant-current motor increases its speed as the load decreases, and if the load is reduced considerably the speed will reach a dangerous rate. It is for this reason that such a motor cannot be operated without a governor to control its speed.

851. Cannot a constant-current series-wound motor be made self-regulating?

No. Since the current is constant in both the field winding and the armature, the torque is constant regardless of speed, and the least reduction in the external load reduces the resistance to the constant torque, allowing the armature to run away. The speed will increase rapidly until the armature bursts from centrifugal force.

852. What other characteristics have constant-current series-wound motors?

Weakening the field of a constant-current series motor re-

duces the power given out, and also reduces the speed if the load is unaltered. The strength of the field may be easily varied by shunting the series field winding with an adjustable resistance. With a load much above normal the series-wound constant-current motor will not start, but if started with slightly less than full load it will race until the losses due to friction and eddy currents increase the load sufficiently to prevent further increase in speed. The armature of a motor working on a constant-current circuit will not run hot when overloaded because the current remains constant, and therefore the heat which it produces remains constant.

853. How should a constant-current motor be stopped?

By first "bypassing" or shunting the main circuit around the entire machine, and then entirely disconnecting both of its leads from the supply circuit.

WORKING VALUES OF DIRECT-CURRENT MOTORS

854. What effect has the internal heating of a motor upon its efficiency and output?

Only a portion of the electrical energy supplied to a motor is converted into useful mechanical work, part being spent in heating the armature conductors and field-magnet winding and part in iron losses. Therefore, the heating of the windings reduces the efficiency. Since the heating is proportional to the square of the current in the windings and the output is proportional to the current in the armature, any increase in load produces an increase in armature heating equal to the square of the increase in load; there is a limit, therefore, beyond which the load cannot be increased without causing unsafe heating.

855. What relation exists between the speed of a motor and the work performed?

When a motor is running with constant field excitation and constant armature current, the work done is proportional to the speed. With constant field excitation and constant supply

potential, there is no simple direct relation between speed and work except that as the output increases the speed decreases slightly owing to the increased voltage drop in the armature, which reduces the counter electromotive force required.

856. Explain the difference between the total power and the net power of a motor.

The total power is directly proportional to the product of the armature current and the counter electromotive force. The net power delivered is the total power minus the loss in friction at the brushes and bearings, the loss in friction of the moving parts against the air and the losses in the iron parts of the motor, such as the armature core.

857. How is the power or output of a motor determined experimentally?

The simplest method is by applying a Prony brake to the pulley of the motor, supplying the motor with its normal full-load current and voltage, and noting the number of foot-pounds registered by the brake when the motor is running at its rated speed. If the number of foot-pounds thus found be substituted for T in the formula given in Answer 816, which is

$$HP = \frac{S \times T}{5252},$$

and the speed of the armature in revolutions per minute be substituted for S, then the horse-power HP may be easily calculated.

858. How is the input of a motor determined experimentally?

By measuring the voltage across its terminals and the total current delivered to it. The product of the two will give the input in watts. It may be expressed in horse-power by dividing by 746, or in kilowatts by dividing by 1000.

859. How is the efficiency of a motor found?

By dividing the output by the input; that is, dividing the

mechanical power developed by the electrical power applied, both quantities being expressed in the same terms. Thus, if the one is expressed in horse-power, the other must also be in horse-power.

860. What is an average value for the full-load efficiency of a motor of moderate size?

About 85 per cent. In other words, such a motor working at full load converts into mechanical power, available for use, about 85 per cent. of the electrical power supplied to it.

861. What becomes of the remaining 15 per cent. of electrical power supplied to the motor?

It is used up in overcoming the friction, the armature-core losses, and heating the armature and field-magnet windings.

862. How may the friction and iron core losses be determined?

The simplest method is to let the motor run without any load—unbelted—measure the voltage at the brushes and the current through the armature alone. Multiply the current by the resistance of the armature circuit and subtract the result from the voltage at the brushes; the result will be the counter electromotive force. Multiply this by the armature current and the result will be the watts used up by friction and armature iron core losses.

863. How is the power lost in heating the armature winding at full load found?

By multiplying the square of the armature current at full load by the resistance of the armature circuit in ohms. The result will be the watts lost. Dividing this by 746 will give the horse-power lost.

864. How is the power lost in heating the field-magnet winding found?

Either by multiplying the square of the field current by the resistance of the field winding, or by multiplying the field-winding current by the voltage at the field terminals. The result will be in watts.

865. Show by means of a diagram how the losses in a shunt motor vary with the load.

Fig. 312 shows the variation of these losses in a 15-horse-power direct-current shunt motor working on a constant-potential circuit. The field-winding current and the speed being

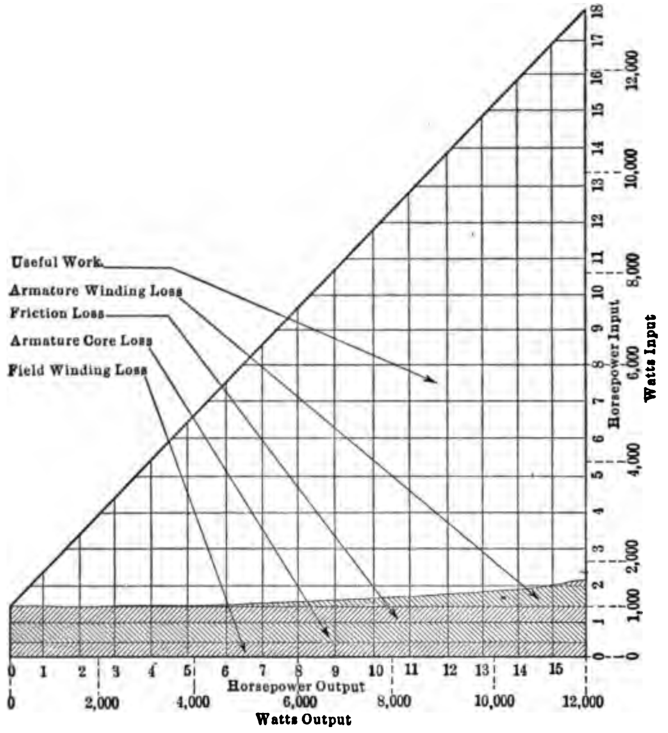

Fig. 312.—Diagram showing Distribution of Losses in a 15 Horse-Power Direct-Current Shunt Motor on Constant-Potential Circuit.

constant at all loads, the losses due to the resistance of the field winding, the friction of the moving parts and the armature-core loss are practically the same for all loads. The armature current, however, will vary as the load changes and this causes the armature-winding loss to vary as shown. The scales at the side of the diagram give in watts, and the equiva-

lent horse-power, the electrical power supplied to the motor. The scales at the bottom give in the same terms the output of the motor.

866. How much electrical power must be given the motor represented by the diagram in Fig. 312 to make it give 4 horse-power?

Follow the straight line from the 4 horse-power point at the base of the diagram up to the slanting line and then follow at right angles a line to the side scale, where it will be seen that the necessary electrical power for this case must be 4000 watts, or about 5.4 horse-power.

867. What is the electrical efficiency of a motor?

The electrical efficiency is the ratio of the total power developed by the motor (not the net power delivered by it) to the total power supplied it.

868. How does the commercial efficiency of a motor vary with the load?

The commercial efficiency decreases as the load decreases. This may be seen from Fig. 312, for at 13.5 horse-power it is $13.5 \div 15.4 = 88$ per cent., and at 4 horse-power it is $4 \div 5.4 = 74$ per cent.

INSTALLATION, WIRING AND OPERATION

869. What general considerations should govern the installation of a motor?

It should be located, whenever possible, in a clean, dry, well-ventilated place, free from dust and liability to injury, and it should be readily accessible for examination and adjustment.

Care should be taken to avoid injury to the motor through neglect or rough handling in unpacking it. Be sure that all accessories, such as pulley, keys, base, rails, rheostat, etc., are removed from the packing boxes.

The base or slide rails should be firmly secured to a rigid foundation, wall or ceiling, as the case may be. The machine may then be attached to the base or slide rails, care

being taken to set the machine so that the armature shaft is level. Machines should never be installed on foundations which vibrate excessively.

870. How should the motor be wired in circuit?

In accordance with the diagram of connections accompanying the machine, or if such a diagram is not furnished, in accordance with the general arrangement shown respectively in Figs. 313, 314 and 315 for shunt-, series- and compound-wound motors.

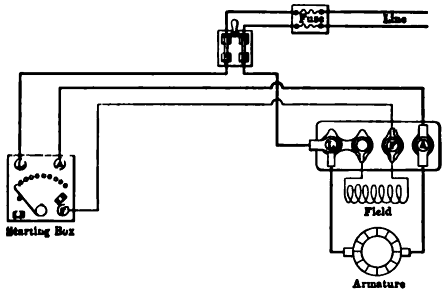

Fig. 313.—Wiring for Shunt Motor and Starting Rheostat.

871. For which direction of rotation is a motor usually arranged when leaving the factory?

Unless otherwise specified, motors are usually tested and connected for a left-hand direction of rotation; that is, when

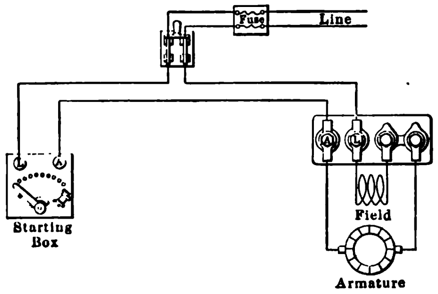

Fig. 314.—Wiring for Series Motor and Starting Rheostat.

facing the machine at the commutator end the top of the armature will turn toward the left. An arrow indicating the

direction of rotation is generally painted on the machine at the commutator end.

872. What preliminaries should be observed before starting up a motor for the first time?

Slowly turn the armature over a few times by hand to make sure that it does not rub or bind, and is perfectly free to revolve. See that the machine throughout is free from dirt or foreign matter, and is properly lined up so that if a belt is used it runs in the middle of the pulley. Check up the connections of the motor and its starting rheostat with a

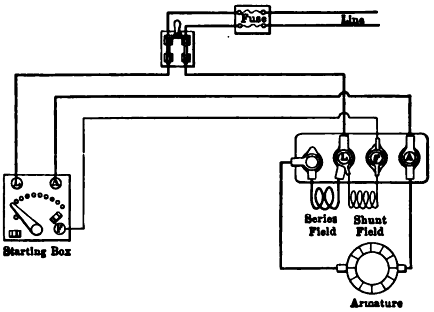

Fig. 315.—Wiring for Compound Motor and Starting Rheostat.

wiring diagram for the case in hand. Fill the bearings with high-grade dynamo oil until the oil gages show that the proper amount of oil has been introduced. Make sure that the oil rings properly carry the oil over the bearing surfaces when the armature is turned.

The brushes should be given the proper pressure on the commutator,—about $1\frac{1}{2}$ pounds per square inch of contact surface. This should be determined by means of an ordinary spring balance, as illustrated and described in Answer 252. The following table will be found useful in determining the approximate pressure that should be given the brushes on the commutator for various sizes of brushes:

For brushes 1 inch or less wide, about $\frac{1}{2}$ pound.

For brushes $1\frac{1}{4}$ inches wide, about 1 pound.

For brushes $1\frac{1}{2}$ inches wide, about $1\frac{1}{2}$ pounds.
For brushes $2\frac{1}{2}$ inches wide, about $2\frac{1}{2}$ pounds.
For brushes 2 inches and over, 3 pounds.

873. What directions should be followed in securing the proper position of the brushes on the commutator?

Motors vary considerably in regard to the position in which their brushes must be placed for the best results. In bipolar motors or motors arranged for rotation in either direction, the position of the brushes should be midway between the pole pieces.

In multipolar machines, a punch mark is generally placed on the rocker arm and two punch marks on the bearing nose. If the motor is to run with a left-hand rotation, the punch mark on the rocker should be over the right-hand punch mark on the bearing nose, and with a right-hand rotation over the left-hand punch mark. Reversible motors have only one punch mark on the bearing, the brushes being set centrally, and these motors should run equally well in either direction without changing the position of the brushes.

874. If there are no punch marks, how should the brushes be placed?

The brushes should be placed midway between the centers of the pole faces, and then shifted backward to prevent sparking as explained in Answer 806, a distance of $\frac{1}{8}$ inch to an inch or more, depending upon the size of the motor.

In bipolar machines there are always two studs or sets of brushes and these must be placed exactly 180 degrees apart. In multipolar machines there are usually as many sets of brushes as there are pole pieces. By a series connection or by a cross connection of the armature winding the number of sets of brushes may be reduced to two and these in a four-pole motor should be set 90 degrees apart, in a six-pole motor 60 degrees apart, in an eight-pole motor 45 degrees apart, in a ten-pole motor 36 degrees apart and in a twelve-pole motor 90 degrees apart.

875. How should a shunt motor be started for the first time?

Throw off the belt, close the circuit breaker, if there is one, and then close the main switch, having first made sure that the starting rheostat handle is in the "off" position. The motor should have a strong field before current is passed through its armature; otherwise, the low torque will delay acceleration and, consequently, the building up of the counter electromotive force, and the prolonged passage of the starting current might damage the armature winding. To guard still further against an injurious armature current, it is customary in starting all but the smallest motors to use a starting rheostat, as mentioned, connected in series with the armature and the source of supply. In very small motors this precaution is not necessary on account of the comparatively high resistance of their armatures, but these are special cases.

Now start the motor by moving the rheostat handle to the first contact, hold it there a moment and slowly pass to each successive contact until all resistance is cut out. Give the motor time to speed up before passing from one contact to another. Allow the motor to run without load for a time to make sure that it is in proper working order. If the machine operates at a speed higher than that on the nameplate, or does not appear to be working properly, turn off the current by opening the main switch. Do not continue to run the motor without locating and remedying the trouble. When the armature has attained full speed, see that the oil rings revolve properly and that they supply the journals with oil, as otherwise the bearings will run hot. Feel all joints and connections. If any one is warmer than the others, the connection is imperfect and should be tightened.

Care should be taken that the shunt-field circuit of a self-excited or separately-excited shunt motor is not opened during the operation of the motor, else the armature will tend to run away if lightly loaded, and flash over if heavily loaded. If the shunt-field circuit is opened when carrying current and

the motor is not operating, there is danger of the field coils being punctured. If it is necessary, therefore, to break the field circuit, it should be done slowly, allowing the arc formed to die out gradually.

876. What important points should be observed in operating a shunt motor after it is started?

It sometimes happens, through accident to the generator, that the current supply to a motor is stopped for a time. In such an event, if the motor is left directly connected to the supply circuit, a sufficiently strong current may rush through its armature winding when the generator is again started, to damage it. Then, too, should the shunt field circuit of the motor be accidentally opened while the motor is in operation, the counter electromotive force would cease and the full voltage of the circuit would be applied unimpeded to the armature. If the supply circuit were not immediately opened, the winding of the armature would probably be burned. To guard against such accidents, a starting rheostat, such as described in Answer 725, should be selected which is provided with mechanism that will operate, under the conditions mentioned, to protect the motor.

877. How should a series-wound motor on a constant-potential circuit be started?

A starting rheostat must be connected in series between the machine and the supply circuit to prevent too great a rush of current in starting. The series-wound motor on a constant-potential circuit does not have a constant field strength and does not run at constant speed, like a shunt-wound motor. If the load is taken off entirely, its speed may become so high as to cause the armature to destroy itself. The series motor should, therefore, always be started and operated with a considerable load.

878. If the motor fails to start when the rheostat arm is turned to the first few contacts, what should be done?

If the motor fails to start, it may be due to being improp-

erly connected, or if the connections are correct and secure, there may not be voltage in the supply wires. If the field circuit of a shunt-wound motor is properly connected, the pole pieces should be strongly magnetic when the main switch is closed. They can be tested by holding a piece of iron near them and noting the attraction. With an iron long enough to bridge the gap between poles and one end touching a pole face, the other end of the iron should be strongly attracted to the adjacent pole. If this is not the case between any two poles of the motor, the field coils are not properly connected.

879. What is the test for voltage in the supply wires?

Connect a voltmeter across them and see if there is a deflection of the pointer. If a voltmeter is not at hand and the current is normally supplied at 220 volts, connect two ordinary incandescent lamps in series and then connect them temporarily across the supply wires. If they light, the voltage supply is all right; if they do not light and their filaments are not broken, there is no voltage in the supply wires or the voltage is much too low. On a 500-volt circuit five lamps must be used in series instead of two.

880. On a three-wire system is it not possible for lamps to burn properly but the conditions of the circuit be such as to prevent the running of a motor?

Yes. If one of the two generators supplying the system becomes reversed, both the outside wires of the supply circuit will be of the same polarity. Although lamps connected between either outside wire and the center wire of the system will light, a motor connected to the outside wires of the system will not run.

881. Are there any other misleading conditions of a similar nature on a three-wire system?

Yes. One of the outside wires of a three-wire system, Fig. 316, may be open at x, and yet a motor c connected beyond the break may get current at 110 volts through the lamps l con-

nected between the outside wire on the same side as the break and the center wire. A 220-volt motor operating in this way will not be able to run anywhere near full speed, owing to the

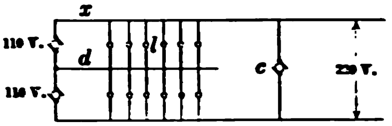

Fig. 316.—Diagram showing how a Motor may operate under Misleading Conditions on a Three-Wire System.

supply voltage being 110 instead of 220, and the resistance of the lamps *l* being in series with it.

The center wire *d* of a three-wire system may be open and yet not affect the operation of a motor at *c*, because the motor is connected to the outside wires only.

882. If it is suspected that friction trouble is preventing the motor from starting, what should be done?

The cause of the friction should be ascertained and removed before an attempt is made to run the motor. In starting up a motor after a trouble of this kind, it is advisable to switch on the current just long enough to see if the trouble has been entirely removed before leaving it on permanently.

883. How should the motor be shut down?

Open the circuit breaker or main switch, allowing the machine to slow down of its own accord. Never stop a motor by releasing the lever of the starting rheostat, as this would burn the contacts on the rheostat and might puncture the insulation of the field and armature coils.

884. May the load now be placed on the motor?

The motor, if new, should be allowed to run without load for a day or two so the bearings and brushes may conform themselves to actual working conditions. When ready for the load, place the belt on the pulley and start the motor as before, closely watching the machine and everything connected with it so as to be ready to open the main switch or

circuit breaker the instant there appears to be anything wrong.

When load is first thrown on a machine an ammeter should be in circuit for the purpose of ascertaining whether the machine is operating at its proper load, for if it is overloaded trouble may be experienced. The correct normal load in amperes is stamped on the name-plate mounted on the field frame.

885. What are the indications if the motor will not start on account of too heavy a load?

The fuses melt or the circuit breaker operates; an ammeter connected in circuit with the motor indicates a larger current than that required by the motor at full load; the insulation on the armature begins to smoke. An overload on a series-wound motor does no harm, as the motor will start up as soon as the load is reduced. On a shunt-wound motor, however, an overload is a more serious matter because the armature is liable to burn out.

886. What should be done when it is found that the motor will not start by reason of too much load?

The main switch should be opened at once and the load reduced. If the fuses have melted, they must be replaced with new ones, or if the circuit breaker has opened it must be closed, before closing the main switch preparatory to starting up under a smaller load.

887. Mention any general precautions that should be observed after the load is placed on the motor.

Inspect the motor frequently for the first few days, to guard against hot bearings, loose connections, etc. Keep all parts of the machine free from water, carbon dust and dirt of all kinds. Keep bearings properly filled with oil, and see that they do not leak or throw oil; also see that the oil does not overflow into the machine. Use every precaution to prevent oil from reaching the commutator or the armature windings. At first, the oil in the bearings should be changed once a week; later, two or three times a month.

Cleanliness is particularly essential, both inside and outside the machine. A hand bellows is convenient for blowing out dust, etc., from the inside of the machine, and an oily cloth for wiping dust, etc., from the outside. Cover the machine when not running, to protect it from dust.

888. What troubles are most liable to arise in the operation of a direct-current motor?

Sparking, heating, noise and abnormal speed.

SPARKING

889. In which parts of the machine does the sparking usually occur?

At the commutator.

890. What are the usual causes of sparking at the commutator?

(1) The armature may be carrying too large a current, owing to an overload on the machine, or to friction such as that caused by the armature shaft not turning freely, or the armature striking the pole pieces. A coil in the armature may be short-circuited or reversed, or there may be an open circuit in the armature. Too little resistance in the starting rheostat will cause sparking. If the armature or the pulley is not perfectly balanced, there will be vibrations of the machine which may produce sparking.

(2) The brushes may make poor contact with the commutator, they may have too high resistance, or they may not be at the neutral points.

(3) The commutator may be rough, not perfectly round, or may have some high bars in it.

(4) The field magnets may not be fully excited, or one pole may be stronger magnetically than another.

891. How can one tell whether the sparking is caused by an overload on the armature?

In case of a belted motor the tension side of the belt becomes very tight, and the belt sometimes squeaks owing to its

slipping on the pulley. In either a belted or direct-connected motor an overload causes overheating of the armature, and this latter may be detected without stopping the machine; simply hold the hand in the current of air caused by the rotation of the armature and note the temperature by the sense of feeling.

To determine whether the overload is friction within the machine, stop the motor, and while turning the armature slowly by hand notice if it turns hard at a certain part of each revolution. If it turns hard there is some sort of mechanical obstruction within the machine; if it does not turn hard, the trouble, if an overload, is either a too tight belt or trying to accomplish too much work with the motor capacity available.

892. What are the symptoms caused by a short-circuited coil in the armature?

A short-circuited armature coil becomes much warmer than the others while the machine is in operation and is very liable to be burned out. The motor draws more current than usual, and if the armature be felt when the machine is first shut down, the short-circuited coil can usually be located by reason of its higher temperature.

893. How should trouble due to a short-circuited armature coil be remedied?

By removing the short-circuit. A piece of metal between the commutator bars or between their connections with the armature winding is usually the cause, in which case it is easily remedied. If, however, the trouble is in the coil, the defective coil will probably have to be replaced by a new one.

Generally, the condition of a coil will readily indicate whether repairing or a removal is necessary. When a coil in a low-voltage machine has become injured through careless handling, it may be possible to repair the damage by separating the wires properly and applying a coat of shellac or some good insulating compound. Even in motors of higher

voltage it is often possible in this manner to remove a small trouble without replacing the coil.

894. Describe how to remove an armature coil.

If a coil is entirely burned out, it may be easily removed by cutting it in two, but this should not be done unless it is certain that no part of it can be used again. Formed coils cannot be used a second time if a part of them is cut out. When, however, an accident happens to a hand-wound coil, the good wire in it may, by taking it off, be used again.

895. Is it not advisable to keep a supply of wire on hand in the station for replacing damaged coils?

It is important always to have in the station the proper wire for such coils as may be wound by hand on the armature or on the field coils. A sufficient amount of it to wind at least one or two coils should be provided. When a motor is built up of formed coils, there should always be within reach several coils of the different kinds that may be needed. Besides these should also be provided the shellac, oil, tape and whatever other materials may be necessary in repairing any particular machine.

896. Explain how to replace an armature coil.

The manner of replacing coils depends altogether on their construction and the type of the machine in question. When a coil is to be wound on by hand, care must be taken to notice how the old coil was wound on and connected, and the new one must be put on in the same manner.

897. What are the symptoms of a reversed coil in the armature?

The motor draws more current than usual, but the reversed coil is no warmer than the other coils. To test for a reversed armature coil, stop the motor and pass a direct current in the same direction through each of the armature coils in succession by connecting the source of the testing current with adjacent commutator bars. Hold a compass needle over the coil undergoing test, and when applied to a reversed coil

the needle will point in the opposite direction to that when applied to the other coils.

898. State how trouble due to a reversed armature coil should be remedied.

By changing the terminal connections of the reversed coil so that they correspond to those of the other coils.

899. How is it possible to know whether sparking is caused by too little resistance in the starting rheostat?

If there is sparking from this source, it will occur only in starting up the motor. The motor will also start suddenly.

900. What should be done to determine whether a motor has a poorly balanced armature or pulley?

A poorly balanced armature or pulley usually causes vibrations of a stronger and more thoroughly distributed nature than those due to other causes and the vibrations increase with the speed of rotation, so that the trouble may be recognized in this way. If the indications point to the armature, the pulley, or both armature and pulley being unbalanced, they should be removed from the machine and tested separately, as described in Answer 967.

901. How can a poorly balanced armature or pulley be remedied?

As explained in Answer 967.

902. What precautions should be taken in removing the armature from a motor to avoid injury to the armature coils and commutator?

After taking off the pulley and unscrewing and removing the top caps from both bearings, a rope should be looped around both ends of the armature shaft as shown in Fig. 317. As soon as the armature has been lifted out from the frame sufficiently far to permit it, a wooden strut should be used as shown in Fig. 318 at *s* to keep the rope from pressing upon the armature coils.

The armature should never be laid on the bare floor; a heavy pad of carpet, burlap or canvas should be used. Care should

be taken not to rest the weight of the armature on the commutator bars. In replacing the armature in the frame, if it be necessary to rest it upon the pole pieces, a sheet of thin fiber or press board should be placed between the armature and pole pieces as in Fig. 319 to prevent injury to the windings of the armature. Precaution is also necessary not to scratch that part of the shaft which is to go in the bearings, as this will

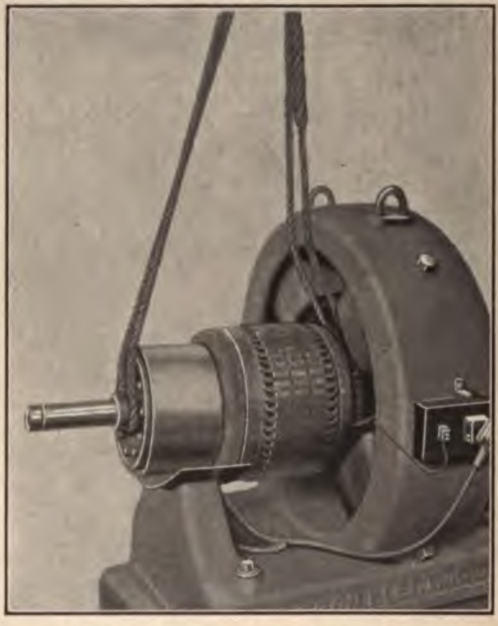

Fig. 317.—Removing the Armature.

cause cutting and heating. In motors of small size the removal of the armature is, of course, a much simpler matter, as it can then be lifted by hand.

903. If it is important that the motor be not shut down, can sparking due to vibrations of the machine be reduced temporarily?

It can be partially overcome by giving more tension to the brushes so they press more firmly upon the commutator. This,

however, is liable to develop considerable heat, both in the brushes and commutator, and should be resorted to only in cases of emergency. It may be found that the vibrations are due to an unstable base or foundation, in which case the trouble may be overcome without much difficulty.

904. Is there not always some sparking at the commutator of direct-current motors?

There is usually some sparking in all machines provided with commutators, but it is nevertheless a feature to be care-

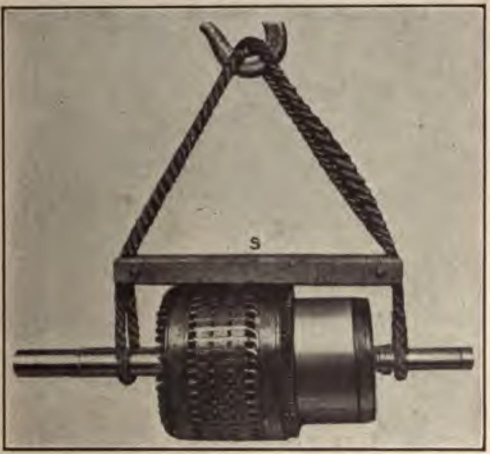

Fig. 318.—A Wooden Strut keeps the Rope away from Armature Windings.

fully watched and reduced to a minimum, inasmuch as it tends to destroy the brushes and commutator, causes trouble in the regulation of the machine and produces heat in the parts at which it occurs. A motor in perfect working condition should run without any sparking.

905. If the sparking is due to the brushes, how should it be remedied?

If the brushes do not conform to the curvature of the commutator, or are not smooth, a strip of coarse sandpaper should be wrapped face outward once around the commutator, allow-

ing it to lap a couple of inches over the first turn. By slowly turning the armature while the brushes are thus pressing on the sandpaper around the commutator, the contact surface of the brushes will be given the desired curvature. Then remove the coarse sandpaper and give each brush the necessary smoothness by drawing back and forth under it a short strip of fine sandpaper, keeping the back of the sandpaper through-

Fig. 319.—A Sheet of Fiber wrapped around the Armature facilitates its Replacement without Injury.

out its length close against the surface of the commutator. Use a bellows to blow out the carbon dust from the commutator, brushes and brush holders, and adjust the tension spring of the brush holders so the brushes are given the proper pressure upon the commutator as explained in Answer 872.

Oil is sometimes applied to the commutator for the purpose of reducing the noise or chattering of the brushes and when much of it has been applied the brushes become sticky and readily collect dirt on their contact surface, producing spark-

ing. They should then be cleaned by a cloth moistened in oil or benzine.

906. Is there any simple way of ascertaining whether sparking is caused by brushes of too high resistance?

Yes, this may be detected by the abnormally high temperature of the brushes. Such brushes should be replaced by others having a lower resistance.

907. How is one to know if the brushes are at the neutral points?

If there is sparking, and by shifting the brushes slightly around the commutator by means of the rocker arm the sparking is decreased, it proves that the brushes were not at the neutral points. In case, however, the brushes are not spaced as explained in Answer 874, no amount of shifting will place them at the neutral points. They must then be readjusted before satisfactory results can be secured.

908. What causes the commutator to become rough or uneven?

Unless there is some end play to the armature shaft, allowing it to move in and out in accordance with the motion imparted to it by the belt, the brushes will bear continuously on the same portion of the commutator and will in time cause it to become grooved and roughened. Hard particles in the carbon brushes will scratch the commutator. And it may be that the commutator has been turned out of the shop in a rough state.

Sometimes one or more bars in the commutator are of softer metal than the others and, by wearing sooner, cause the commutator to become flattened or eccentric. There will then be a gap between the brushes and the commutator at this point, resulting in sparking.

A high bar in the commutator, or a projecting strip of mica between the bars, which on account of its hardness does not wear down as quickly as the bars, will throw the brushes off the surface of the commutator during the rotation of the latter, and this will cause sparking.

909. What is the best guide with reference to the condition of the commutator and brushes?

The appearance of the commutator. If there is perfect contact between the brushes and commutator, the surface of the latter will take on a glossy brown or bronze appearance. A rough commutator, however, will generally announce itself by causing the brushes to make a chattering noise; this is particularly the case in high-speed motors. With an uneven commutator there will be a noticeable rising and falling of the brushes when the armature is rotating slowly.

910. What precautions should be observed to keep the commutator in good condition?

Wipe its surface occasionally with a soft cloth or piece of waste to remove accumulations of dust. Dust is a direct cause of poor contact between brushes and commutator; it is therefore responsible for much of the sparking, roughness and heating of a commutator. After removing the dust from the commutator, it is advisable to place a few drops of good machine oil or vaseline on a clean portion of the wiping cloth, and while the commutator is in motion, move the cloth slowly across it so the oil will spread lightly over its entire surface.

911. If the commutator is rough, how should it be smoothed?

Place a piece of fine sandpaper in a block of wood which has been hollowed out to fit the curvature of the commutator and press it against the commutator while the armature is in motion. If the commutator is very rough or unevenly worn, sandpaper does very little good. It is then necessary to use a file.

912. Explain how to use a file in smoothing the commutator.

The grade of the file used should depend on the work to be done, but it must be one that is least liable to be clogged by the copper. Oil must be used freely to avoid heating and choking, and to make the file cut well. The commutator

must not revolve too rapidly and the file must be held properly. The hand which holds the file from slipping should be in a position where the commutator tends to pull rather than push the file. Failure to observe this rule may result in serious injury to the hand, or in a piece gouged out of the commutator.

To make a file safer and more serviceable for this work, a file rest should be provided. Without a file rest it is impossible to file the commutator surface level from end to end, and the flat places will not be taken out but made larger; there is also more danger and difficulty in doing the work. Where there are several motors just alike, one file rest may be used for all of them.

913. What kind of a file rest should be used and how should it be fastened in place?

A convenient form of a file rest bolted in place is shown in Fig. 320. It consists of two pieces of iron, *c* and *c*, each

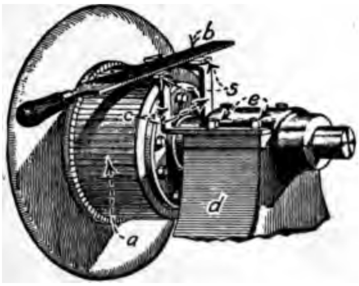

Fig. 320.—Form of File Rest convenient in Smoothing the Commutator.

provided at one end with an adjustable piece *s*. Each of the pieces *c* and *c* is attached to one side of the bearing *d*, and is held in position by the cap bolts *e*, etc. A file *b* is laid across the pieces *s* and *s*, which are so adjusted that the file will just touch the commutator *a*.

The separate parts of the file rest are more clearly illustrated in Fig. 321, where *a* represents one of the pieces of

iron, provided with slots *b*, etc., for the reception of the cap bolts. The other end is made adjustable by being provided with an extra piece *c*, the height of which is adjusted by screws *e*, etc. The piece *c* after having thus been raised to the proper height is held in position by the screws *d*, etc. The part *c*, consequently, rests on the screws *e* and *e* and is held on them

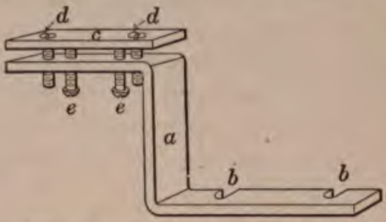

Fig. 321.—Detail of File Rest in Fig. 320.

by the screws *d* and *d*. The latter screws are countersunk so that they will not be in the way of the file. The bar *a* should be of such dimensions that the pressure on the file will not cause it to move.

914. If the commutator is eccentric or too rough to be smoothed evenly by means of a file, what should be done with it?

It should be turned down by means of a lathe. If the arma-

Fig. 322.—Commutator Truing Device.

ture is large and difficult to remove from the machine, a portable lathe or truing device can be attached directly to the brush-holder bracket after the brush holders are removed, as shown in Fig. 322, and the commutator turned down without removing the armature from the motor. The brush-holder

bracket should be braced at the outer end by heavy wooden blocks, as shown at *m* and *n,* to prevent vibration.

Instead of a regular cutting or lathe tool, two pieces of carborundum stone, *a* and *c,* are employed. These are clamped in the carriage *i* and moved back and forth across the face of the commutator *d* by a screw feed rotated by hand, the handle *r* being provided for the purpose. The armature is rotated at the same time at normal speed and pressure of the stones against the commutator is obtained by the cross screw feed.

If the armature is small and easy to remove from the machine, it should be placed in an ordinary stationary lathe and the commutator turned down in the usual manner.

915. In case it becomes necessary to remove the commutator from the armature, how should this be done?

The simple device shown in Fig. 323 is convenient for this

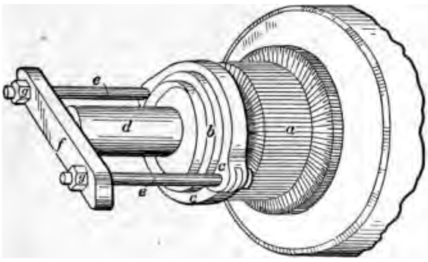

Fig. 323.—Single Arrangement for Removing the Commutator from the Armature.

purpose. It consists of two pieces of iron *c* and *c,* shaped to fit back of the collar *b* on the commutator spider. Through holes in the ends of *c* and *c* are passed bolts *e* and *e,* and over the outer ends of the bolts is slipped the bar *f* which bears against the shaft *d.* Before commencing to remove the commutator it is necessary to have all the armature connectors disconnected from it. By screwing up the nuts *g* and *g,* the spider and commutator will be drawn off. After producing the first strain on the bolts, however, it may be necessary to give the commutator a light rap to start it.

916. What characteristic features are present when the sparking is caused by weak field magnets?

The speed of the motor will be unusually high with weak field magnets unless the magnetism is very low or lacking altogether, in which case the motor will run very slow, stop or perhaps run backward. If the pole pieces are tested by holding a piece of soft iron near them there will be little, if any, attraction.

917. How may the trouble be definitely located?

Place wooden chips under the brushes so they do not come in contact with the commutator, and with the field rheostat short-circuited, close the field coils upon the supply circuit. If upon opening this circuit there is no spark, there is a broken wire or connection somewhere in the circuit.

If there is a spark, the circuit is not broken, but one of the magnet coils may be short-circuited. This may be determined by testing with a piece of soft iron which, when held between the pole piece of the short-circuited coil and the adjacent pole piece, will be attracted to the latter, but not to the former. Another method of testing for a short-circuited field coil consists in passing a current through the field circuit and measuring the drops of potential across the different coils. A short-circuited coil will show little or no drop in comparison with the others. A short-circuited coil may be caused by its wire being grounded at two points on the frame.

One of the field coils may be reversed, producing a weak field. This can be determined by passing a current through the field circuit and moving a compass needle from one pole piece to the other in succession. The needle will reverse its direction at each succeeding pole if none of the coils is reversed.

HEATING

918. Is there not always some heat developed in connection with the operation of direct-current motors?

All motors in operation develop a certain amount of heat which cannot be prevented and which is not therefore con-

sidered a defect. It is only abnormal heating in a motor that need cause apprehension.

919. Explain why a motor in perfect running order develops heat while in operation.

Considering the motor electrically, heat is developed at the commutator and brushes and in the field and armature coils because it is impossible to force a current of electricity through a conductor without heating it.

Considering the motor mechanically, heat is developed in the bearings, commutator and brushes by reason of friction between moving parts.

Considering the motor magnetically, heat is developed in the iron portions, such as the frame and magnet cores, on account of the passage of magnetic lines of force through them.

920. Is it an easy or a difficult matter to locate the cause of abnormal heating in a direct-current motor?

It is often difficult because both the defective and perfect parts become of practically the same temperature owing to the ease with which heat is conducted through and between them.

921. How should such a case be treated?

Stop the motor until it becomes perfectly cool. Then start it up and operate it under full load for about five minutes. Stop it again and carefully but quickly test each part for abnormal temperature by the sense of feeling.

922. Give some rules to guide one in testing for temperatures by means of the hand.

The ability to determine accurately in this manner the amount of heat developed can be acquired only by experience. If the hand can comfortably be held on the iron portion of a machine for several seconds, its temperature may be considered as being within the safe limits.

In connection with this test the condition of the hand must be taken into consideration as well as the conductivity for

heat of the surface touched. Inasmuch as the back of the hand is far more sensitive than the palm, more reliable results will be obtained by testing with the back of the hand. If the surface of the iron is rough there will be more radiation than if it is smooth and, in consequence, its internal temperature may be higher than the sense of touch would lead one to suppose. Then, too, any paint on the surface of the iron also lowers to a considerable extent the conductivity of the internal heat.

923. **How can more accurate results be secured than by the sense of feeling?**

By using thermometers.

924. **Give some rules for testing motor temperatures by means of thermometers.**

The bulb of the thermometer should be placed against the surface of the part in which the temperature is desired and it should be protected from outside influences by a covering of cotton waste, the whole being held in position either by hand or tied by means of a string.

In connection with this test it is well to note the temperature of the surrounding air at the time the other reading or readings are taken, for the atmospheric temperature has, of course, a direct bearing upon the temperatures of the various parts of the machine.

925. **What temperatures of the different parts of a direct-current motor would be considered abnormal?**

For the field or armature, over 50 degrees Centigrade above the surrounding air temperature; for the commutator or brushes, over 55 degrees Centigrade above the surrounding air temperature; for bearings or other parts of the machine, over 40 degrees Centigrade above the surrounding air temperature.

926. **Is there any other method of obtaining temperatures of the parts of a motor?**

Yes, there is an electrical method particularly well adapted

for securing the temperatures of the field and armature coils. The inaccessibility of these parts renders the hand and thermometer methods rather inadequate for the purpose. The electrical method is often used as a check on the temperatures obtained on the field and armature coils by means of thermometers.

927. Explain how to obtain the temperatures of the field and armature coils by the electrical method.

After the motor has been run under full-load conditions sufficiently long to insure the maximum temperatures being reached, the machine is shut down and a moderate direct-current voltage applied first between any two opposite commutator bars and then between the terminals of the field coils. In each case the amperes of current are carefully noted on an ammeter, and at the same time the drop in pressure between the points of application is also read on a voltmeter. Having, then, the current through the armature coils and through the field coils, and the respective pressures across them, their respective resistances hot may readily be calculated by dividing the latter values by the former ones.

In performing this test care must be observed that the testing voltage does not exceed the normal voltage for which the armature winding or the field winding is designed, in order that the testing current does not injure or unduly increase the temperatures of these parts; it is also necessary to note by aid of a thermometer the temperature of the surrounding air in degrees Centigrade at the time these measurements are being taken.

Having, then, at an atmospheric temperature of T°, the resistance in ohms which we will designate R_{T°, the next step is to calculate what this resistance would be at zero degree Centigrade. Designating this unknown quantity by Ro°, the formula used is

$$Ro^\circ = \frac{R_{T^\circ}}{1 + 0.004\, T^\circ}.$$

By substituting for the terms on the right-hand side of

this equation their proper values, and dividing the numerator by the denominator, the value of Ro° will be obtained. This value, together with that of R_{T°, when substituted in the equation

$$T = \frac{R_{T^\circ} - Ro^\circ}{Ro^\circ \times 0.004}$$

will give the temperature in degrees Centigrade, at the time the measurements were taken, of the armature coils or of the field coils, depending upon whether R_{T° is the resistance hot of the one or the other.

928. If the thermometer readings in Answer 927 were taken on Fahrenheit thermometers instead of on Centigrade thermometers, would the results be affected?

They would. If, however, the Fahrenheit readings be converted into Centigrade by the process described in Answer 39, and these converted figures be used in the calculations, the results will be the same as before.

929. How long does it require a motor working under full-load conditions to attain maximum temperatures in its various parts?

Small motors attain their maximum temperatures sooner than larger motors. Ordinarily, about four hours is sufficient for small motors and from six to eight hours for large ones.

930. Is it possible to detect abnormal heating in a motor by any method not yet mentioned?

Yes, by the sense of smell. When the heating has reached this stage of development, the limit of safety has been far exceeded. Trouble asserting itself in this manner may usually be located in the field or armature coils as the insulation on these windings when subjected to undue heat gives forth a very pungent odor not easily mistaken. If the machine is not shut down at once, the trouble is liable to increase until smoke is visible and the damage irreparable.

931. What are the general causes of abnormal heating at the commutator?

The defects previously mentioned as causing sparking at

the commutator will also raise its temperature. They constitute the general causes of abnormal heating at the commutator.

932. **How should these general causes of abnormal heating be removed?**

By removing the source of the sparking as previously explained.

933. **Does not the appearance of the commutator serve as a guide to the direct cause of the heating?**

It does if the trouble is with the commutator. For example, if there are burnt spots on the surface of the commutator, there is probably dirt or foreign matter on it which should be removed. If, when the current is applied, small sparks can be detected in the insulation between the commutator bars, there is either foreign matter between the bars or the insulation itself has become defective. In the former case the troublesome particles should be removed and in the latter case a new commutator will probably be necessary.

934. **Is a hot commutator sometimes caused by trouble in other parts of the motor?**

Yes.

935. **What usually causes the brushes to become abnormally heated?**

Loose connections in the brush holders or between the brush holders and the brush-holder cables, decomposition of the brushes at their contact surfaces, or carbon brushes of too high resistance.

936. **What should be done in case the brushes are of too high resistance?**

Some improvement may be noticed if the brush holders are set lower so as to make that portion of the carbon through which the current passes as short as possible. Other methods of correcting this trouble consist in providing brushes of larger cross-section, in using a greater number of brushes and brush holders on each stud, and in increasing the con-

ductivity of the carbon brushes by using copper in one form or another in connection with them.

In case one of the carbon brushes is found to heat more than the others, a comparison of its resistance with that of one of the others will show at once if the difficulty lies in its conductivity. If its relative resistance is found to be high, advantage may be taken of the remedies just given for decreasing its resistance.

937. To what cause can abnormal heating of the field coils usually be traced?

To the passage through them of a larger current than they are designed to carry.

938. What would be the heating effect if one of the field coils was short-circuited?

The short-circuited coil would be cooler than the others, and its pole piece would be weaker magnetically.

939. Is there a more accurate method of locating a short-circuited field coil than that mentioned in Answer 938?

Yes. To make absolutely sure whether a field coil is short-circuited, measure the resistance of each one by the drop method. This consists in passing a direct current, maintained constant by means of a rheostat and ammeter, through the field coils connected in series and measuring by aid of a voltmeter the drop in pressure across the terminals of the individual coils. If there is a variation of more than 5 or 10 per cent. between the voltmeter readings, there need be no doubt but that the coil showing the low reading is short-circuited.

940. How may a short-circuited field coil be remedied?

If the trouble lies at the terminals of the coil it is usually easy to bend or insulate them without removing the coil from the pole piece; otherwise, it should be taken off and rewound.

941. What are the causes for high temperature in the pole pieces?

Either heat conveyed to them from other parts of the

machine which have reached a high temperature or eddy currents in the pole pieces.

942. Describe how eddy currents are developed.

Changes in the magnetic condition of the pole pieces due to a variation in the field current through the magnet coils are responsible for the development of eddy currents. The eddy currents travel at right angles to the lines of force of the field. They penetrate into the interior of the pole pieces, although not to a great depth, and heat the iron cores.

943. What harm is done if the pole pieces reach a high temperature?

They raise the temperature of the field coils and so increase their resistance.

944. How is it possible to tell whether hot field coils are caused by eddy currents in the pole pieces or by too large a field current?

If eddy currents are causing the trouble, the temperature of the pole pieces will be higher than that of the field coils. A comparison of the respective temperatures of pole pieces and field coils may approximately be obtained by the sense of feeling, if due allowance is made for the difference in conductivity between the iron of the former and the insulation of the latter. A more accurate comparison of temperatures can, of course, be made by means of thermometers properly applied.

945. What can be done to eliminate eddy currents from the pole pieces?

The reconstruction of the pole pieces is the only practical remedy. They should be laminated by building them up of plates or disks stamped from soft sheet iron, instead of forming each core of one solid mass of iron. The plates are enameled or painted on both sides, and when dry are bolted tightly together and cast in with the frame. The enamel on the plates acts as a resistance to the eddy currents and checks their formation. It does not, however, impede the flow of

the lines of magnetic force through the pole pieces, because these lines pass lengthwise along the plane of the plates.

946. Are eddy currents ever responsible for unduly raising the temperature of the armature?

Yes, especially when they form in the armature core. In this case there is no noticeable sparking, but there is a higher temperature in the core than in the surrounding coils. The machine also requires more than the usual amount of current to run it at no load. As in the similar case with the pole pieces, relief can be obtained only by laminating the iron core.

If the motor is of large capacity, carrying heavy armature conductors, eddy currents may also develop in them. This trouble may be distinguished from that just mentioned by a higher temperature in the conductors than in the core. It will be necessary to subdivide the conductors into strands or strips, twist them about each other, and sink them into slots in the armature core in order to overcome the difficulty.

947. What other causes are sometimes responsible for excessive heating of the armature?

Heat may be developed in some other part of the machine and be transmitted to the armature by conduction. Then, too, the motor may be overloaded and carry too much current in the armature.

948. What effect has dampness upon raising the temperature of armature coils?

If the armature coils become damp their insulation is lowered, but their temperature will not be increased.

949. How should damp armature coils be dried?

By passing a moderate current through the coils for a considerable length of time, or by baking the armature in an oven. In either case the drying process should be continued until the insulation resistance of the windings measures over 1 megohm.

950. Which method mentioned in Answer 949 is preferable for drying out armature coils?

The latter, because it is more effective unless a comparatively strong armature current is used, in which case there is danger of the shellac melting and running and the insulation becoming charred or burned.

951. If the bearings become too warm, what may be the cause of the trouble?

The bearings may fit too closely around the armature shaft; in a new motor they may be out of line; there may be foreign matter in the bearings.

952. How may trouble in the bearings be tested?

By slowly turning the armature around by hand to see if it sticks, or when shutting off the power noticing if the armature comes freely to rest.

953. What are the remedies for troublesome bearings?

Bearings which fit too tightly must be reamed out or scraped, or the armature shaft placed in a lathe and turned down or filed.

If the bearings are out of line with each other the motor should be shut down and the bolts holding the bearings in place partially unscrewed to allow the bearings to find their proper position. When they have done so, and the clearance between the armature and pole pieces is the same on all sides, the necessary adjustments must be made for maintaining the bearings in this position. If the motor is provided with self-alining bearings which, as their name implies, are automatic in action, and which are now commonly used on all high-grade machines, little or no trouble need be anticipated from this cause.

Dirt or other foreign matter in the bearings is liable to result from unfiltered oil being used, or when the room is not kept free from dust and dirt. A careful examination of the shaft will show whether this trouble exists, as there will be scratches on it when such foreign matter is present. To

improve conditions the shaft or bearings must be taken out and cleaned.

954. What is, perhaps, the most common of all causes for abnormal heating of the bearings?

Deficiency of oil in the bearings is the most common of all causes of hot bearings. The deficiency may be due to a defect in the oiling rings on the shaft, to a stoppage or leak in the oil passages, or to empty oil cups. Usually this defect is easily made right, the nature of the trouble suggesting the remedy to apply.

955. Could a very tight belt cause the pulley bearing to heat up?

It could.

956. How may the trouble referred to in Answer 955 be detected and remedied?

It may be detected by the unequal temperatures of the commutator and pulley bearings, the latter being the warmer. If the belt has not been run tight very long, the bearing will probably not have become worn sufficiently to require renewing, but in any case the tension of the belt should be lessened either by employing larger pulleys and a lighter belt or by decreasing the load on the motor.

957. If the bearings are very warm and the armature shaft turns more easily at one point of a revolution than at another, what is probably wrong?

The armature shaft is probably bent.

958. What is the remedy for a bent armature shaft?

The easiest, cheapest and, in fact, the only satisfactory way to correct this trouble is to replace the defective shaft with a new one properly turned.

959. Are there any other shaft troubles that may produce hot bearings?

Yes, the shaft may not have sufficient end play or it may be cut or roughened.

960. Why is end play of the shaft necessary to keep the temperature of the bearings low?

If there be no end play, or free lengthwise movement back and forth, of the armature shaft in the bearings while the motor is in operation, the collar, shoulder, or pulley on the shaft is apt to press continually against the bearings and cause them to become heated.

961. What should be done to correct end-play trouble?

A slight change in the line-up of the belt may improve matters. It may, however, be necessary to file the abutting surface of the bearing or change the position of the pulley or collar along the shaft to secure satisfactory results.

962. In case the shaft is cut or roughened, what should be done?

The shaft should be placed in a lathe and filed or turned smooth. Care must be taken, however, not to remove more metal than is absolutely necessary, else the bearings will not fit and they will have to be renewed. In any case it is necessary to have them perfectly smooth before the repaired shaft is placed in position.

963. Is a bearing liable to become hot by conduction of heat from some other part of the motor?

It is. If the bearing on the commutator side of the machine is becoming heated from no apparent cause, an inspection of the commutator and armature should be made; or if the bearing on the pulley side of the machine is hot, the pulley may be suspected. When it is found that some part has a higher temperature than the bearing on that side of the motor, the proper remedy applied to the defective part will indirectly lower the temperature of the heated bearing.

NOISE

964. What usually causes noisy operation of direct-current motors?

Mechanical defects.

965. What is the cause of a rattling noise, and what should be done to stop it?

A rattling noise is usually caused by parts which have become loose, owing to the loosening of screws or nuts. Guided by the loudness of the noise, a thorough inspection should be made of the binding posts, bearings, and other parts of the machine in which screws and nuts constitute an important feature. If such parts are producing the noise they are loose and vibrating; consequently, by feeling around them while the machine is in operation it is easy to judge of their responsibility for the trouble. On the other hand, if the machine is not running, the shaking of questionable parts will provide the desired information.

If the noise is in the bearings it is generally due to looseness of the armature shaft in the bearings caused by the wearing of the latter. The remedy, of course, is to refit the defective bearing or bearings. If the noise is caused by loose nuts or screws, the remedy consists merely in tightening them thoroughly.

966. If the noise is accompanied by very noticeable vibrations, where is the trouble likely to be?

If the vibrations are generally distributed over the entire machine and increase in intensity with the speed of the armature, the noise is likely to be caused by a poorly balanced pulley or armature.

967. How should a pulley or armature be tested and remedied for an unbalanced condition?

Remove the pulley and armature from the machine and test them separately. The armature can best be tested by placing it so that its shaft is supported at the ends upon two knife-edge or A-shaped iron rails, *a* and *c*, Fig. 324, placed flat and parallel to each other. Then, if the armature is poorly balanced, the heavy side will cause rotation except when this side happens to be downward. By setting the armature at rest on the knife edges with different points

around its periphery placed upward, the weighty side may be easily ascertained. The trouble may be remedied either by soldering some lead on the lighter side, or by filing or boring holes in the heavy side.

A shaft should then be provided temporarily for the pulley

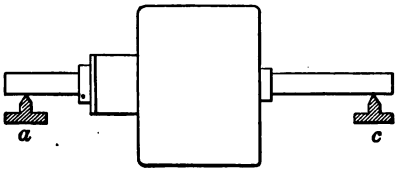

Fig. 324.—Method of Testing an Armature for Unbalanced Condition.

in order that it, too, may be tested; if necessary, it may be balanced in the same manner as described for the armature.

968. State how noise produced by the pulley, belt or shaft collar striking against the bearings of the machine can be easily detected.

By pushing the shaft or belt away from the one or other of the bearings with a stick while the motor is running and noting if the noise ceases.

969. How may noise produced as mentioned in Question 968 be stopped?

The trouble may usually be overcome by changing slightly the direction of travel of the belt. However, if this change does not improve matters, shifting the pulley on the shaft or filing off the shoulder of the bearing, as the case may be, will probably effect the desired result.

970. What kind of noise is made by the pounding of the jointed portion of a belt against the pulley?

A loud thump which occurs but once during each revolution of the armature.

971. Does not the armature when striking against the pole faces make a similar noise?

Yes, but it is less of a thump and more of a scraping noise.

972. How should a trouble of the nature mentioned in Question 971 be investigated?

Usually, an examination of the armature surface will determine if it has been striking the pole faces. Great care should be taken to make this examination thorough, for the danger of damage to the armature when it comes in contact with the pole faces is very great. Another, and perhaps a better, test consists in removing the belt or power connection from the armature shaft, and while slowly turning the armature by hand, observing whether or not it sticks at any point.

973. How should a trouble of the nature mentioned in Question 971 be remedied?

If the trouble is caused by one side of the armature winding projecting abnormally, it may be remedied by binding down the bulging part with a wrapping of iron wire which should extend around the armature body but be well insulated from it at all points. If the armature is out of center, it may be possible to adjust the bearings so there is a uniform clearance between the armature surface and each of the pole faces. Sometimes the trouble lies in one or more of the pole faces projecting abnormally; in this case it will be necessary to file out the projecting portions.

974. What is indicated by a hissing sound produced at the brushes?

Either a dry or sticky commutator, or rough contact surfaces on the carbon brushes. By listening near the commutator, it is easy to ascertain if there is trouble from these sources.

975. If the brushes are making the noise, how may the noisy ones be detected?

By raising one brush at a time while the machine is in operation, and noting if the noise ceases. This test, however, can be applied only to motors having more than one brush on a stud, as otherwise the motor circuit would be opened by the raising of a brush and an arc would be formed that might endanger the experimenter and burn the commutator.

976. How can brushes usually be made to operate noiselessly?

Sandpapering their contact surfaces or applying oil to them at this part will generally reduce the noise. Sometimes it is merely necessary to raise or lower the noisy brush a trifle in its brush holder to stop the hissing sound.

977. How should a noisy commutator be silenced?

Recourse may be had to filing or sandpapering if the commutator is rough, or to the application of a minute amount of oil or vaseline if it is dry. In the case of a new machine having a noisy commutator, it is advisable to run it awhile unloaded until both the brushes and the commutator become adjusted to each other and smooth.

978. What causes other than mechanical ones are responsible for noise in a motor?

If a belted motor is carrying more than its normal load, the belt is likely to slip over the pulley and cause an irregular squeaking sound. In a motor having a toothed-core armature, there is sometimes noticeable a humming noise when the machine is in operation. This results from the passage of the teeth of the core past the field-magnet poles.

979. Cannot objectionable noise caused by overload on a motor be reduced without decreasing the load?

Tightening the belt or applying powdered rosin to that part of its surface which comes in contact with the pulleys may be found to answer the purpose. If, however, these remedies fail, a pulley of larger diameter or a belt having a wider dimension must be employed.

980. Can the humming noise due to a toothed armature core be remedied?

It can be remedied, but only in the reconstruction of the machine, either by reducing the number of ampere-turns in the field winding or by altering the shape of the pole pieces or that of the teeth in the armature core so that the teeth do not all pass the edges of the pole pieces at the same time.

ABNORMAL SPEED

981. What are the usual causes that tend to slow down the speed of a direct-current motor?

Overload; friction between the armature and the pole pieces; friction between the armature shaft and the bearings; a short-circuited coil or ground in the armature; low voltage in the supply circuit.

982. What indications accompany an overloaded motor running slow?

There is usually bad sparking at the commutator, the armature is very warm and in the case of a belted machine the belt is very tight on the tension side and may slip excessively.

983. Is there any remedy for the case mentioned in 982 except reducing the load?

No.

984. What symptoms indicate that friction between the armature and the pole faces is keeping down the speed?

A roughened armature surface; a tendency of the armature to stick when turned slowly around by hand, or a scraping noise when the armature is rotated.

985. How should friction trouble of this kind be remedied?

By binding down the protruding portion of the armature winding, or by properly centering the armature in its bearings or by filing out the pole faces where the friction occurs.

986. If there is sufficient friction between the armature shaft and the bearings to cause drop in speed, will they not become very warm?

They will, and the armature will be difficult to turn by hand.

987. What remedy should be applied in the case mentioned in 986?

The bearings, if not out of alinement, should be readjusted.

If the shaft surfaces are rough they should be smoothed, cleaned and oiled.

988. How may a short-circuited coil or a ground in the armature be found?

A short-circuited coil in the armature will cause the motor to draw excessive current. A ground occurring at two points in the armature will produce the same effect as a short-circuit, but a ground at only one point will not be noticeable. Continuity tests with a magneto testing set, Fig. 151, made by connecting the terminals of the magneto to the armature core and to the wire of the coil and turning the generator crank, will show up a ground if there is one. If the magneto bell rings, there is a ground; if it does not ring, there is probably not any ground.

989. How should a short-circuited coil be remedied?

If the trouble is due to a piece of solder or other metal between the commutator bars or their connections with the armature winding, the remedy consists simply in removing the solder or the metal. If the short-circuit is in the coil itself, the coil will have to be replaced by a new one.

990. What should be done to remove a ground in an armature coil?

If the ground is at a point where it can be reached, it can usually be remedied by inserting a strip of insulating material between the coil and the core. Otherwise, the coil must be rewound.

991. From what cause may a ground be formed in a motor?

Sometimes a ground is caused by a spark of static electricity, generated by friction between the belt and pulley, puncturing the insulation of a coil.

992. Is there any way to prevent trouble from the static electricity produced by the belt?

If the frame of the motor be connected to earth the static charge will be led directly to the ground before it does any

harm. If it is not desirable to ground the motor frame, a moistened thread, a heavy pencil mark on a piece of unglazed porcelain, or any other high resistance connecting the frame to earth that will carry off a static charge, which is of very high potential and very minute magnitude, but will not allow the passage of an appreciable current, will answer the purpose.

993. What are the usual causes that tend to make a direct-current motor run too fast?

Weak field magnets; too small a load, or too high voltage in the supply circuit.

994. Does a weak field magnet always cause a motor to run fast?

A weak field magnet causes a shunt-wound motor to run fast if it is lightly loaded. If the motor is very heavily loaded, however, a weak field magnet will usually cause it to run slow. In case the field circuit is accidentally broken while the motor is running heavily loaded, it may even reverse the rotation and cause the motor to run backward.

995. Is the speed of a motor likely to become dangerously high owing to its load being light?

It is in the case of a series-wound motor, but not so in a shunt-wound motor. A series-wound motor is therefore generally geared or direct-connected to the load instead of being belted to it, because if the belt should break, the motor would increase in speed until the armature destroyed itself.

996. What special care should be exercised in running series-wound motors to prevent the load being removed?

If the load is not direct-connected to the motor an automatic governor should be used in connection with the motor to reduce the current if the speed becomes too high.

997. What way is there of learning whether a high voltage in the supply circuit is causing the motor to speed-up?

Measuring the voltage across the supply wires with a voltmeter.

998. Where should trouble be looked for if a direct-current motor fails to start?

An open circuit in the motor or in its connections to the supply wires; no current in the supply wires; improper connections; excessive friction between the moving parts; too heavy a load.

999. In what parts of a motor or in its wiring to the supply wires is an open circuit most likely to occur?

One of the wires connecting the field winding in circuit may have slipped out of its connection, in which case the pole pieces when tested with a piece of iron will not attract it. The brushes may not be in contact with the commutator. In the wiring to the supply circuit one or both of the fuses may be melted, the circuit-breaker may be tripped or the main switch open.

1000. What should be done in case an open circuit is suspected?

If the main switch and circuit breaker are closed, open them at once, and investigate the wiring of the motor in circuit, feeling about the connections to see if they are tight. If they appear in good condition, test the voltage in the supply wires with a voltmeter or with incandescent lamps if a voltmeter is not available.

In a shunt motor, if the pole pieces strongly attract a piece of iron held near them when the main switch is closed, it indicates there is current in the supply wires and that the trouble is elsewhere than in the field circuit. This, therefore, obviates the necessity of the voltage test above mentioned. If, however, there is no attraction, do not attempt to start the motor by passing current through the armature until there is indication of a strong field.

With field and voltage normal, attention must next be given the armature circuit. Before testing the armature separately, attempt to start the motor again, and note whether there is a spark at the first contact in the starting rheostat

when the armature circuit is made and broken. With no indication of a spark, there is undoubtedly an open circuit either in the rheostat or in the armature, and these should be tested separately for continuity either with a magneto or an electric bell and battery.

TYPICAL MODERN FORMS

1001. For what kind of service is the four-pole motor shown in Fig. 325 chiefly used?

For driving blowers and exhausters of small or moderate size to which it is direct-connected. This motor is built in

Fig. 325.—Sturtevant Four-Pole Motor. Front Bearing Bracket removed to show Commutator, Brushes, Armature, Etc.

sizes of from 1.5 to 35 horse-power and gives speeds ranging from 368 to 1630 revolutions per minute.

1002. Illustrate and describe the principal parts of the motor in Fig. 325.

Fig. 326 shows the principal parts separately. The magnet frame *m* consists of a cylindrical yoke of cast iron, machined to receive the pole pieces and bearing brackets, and has supporting feet cast solid with it. The bearing brackets, or end covers *u* and *v*, are of skeleton construction held in seats in the magnet frame by four bolts.

The pole pieces *n*, *s*, etc., of which there are four, are through-bolted to the yoke and offset axially from the center to permit the use of duplicate bearing brackets on either end. By taking out the through-bolt *c* of any magnet pole, that pole, with its coil, may be removed without disturbing the armature or dismantling the motor. The pole pieces are built up of soft-steel punchings, held between end plates under pressure. The punchings are of such shape that they provide a support for the field coil, and cast-iron horns are

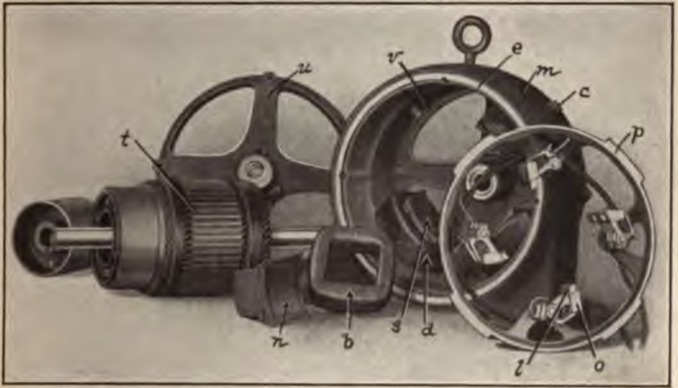

Fig. 326.—Details of the Sturtevant Four-Pole Motor in Fig. 325.

used to eliminate the disagreeable humming while retaining all the advantage of the laminated construction.

The field-magnet coils, *b*, *d*, etc., are shunt-wound, machine-formed and insulated by two layers of heavy tape.

The armature *t* is of the slotted-drum type, built up of annealed-steel stampings, each insulated by a coating of japan. These laminations are assembled on a cast-iron sleeve which is provided with openings for free circulation of air and has an extended hub for the reception of the commutator shell, thus making the armature and commutator a self-contained unit. The armature coils are held in the slots by fiber wedges. The commutator is built up of bars of hard-drawn copper held in a cast-iron shell of spider construction;

amber mica is used for insulation between the copper segments.

The brushes *l*, etc., are of carbon and slide in brush holders *o* of the box type. They are provided with braided copper "pig-tails," which relieve the brush-holder body and springs from carrying any appreciable current. The brush-holder studs are mounted in lugs projecting inward from a ring *p*, which is supported in a machined recess *e* in the magnet frame. It is held in position by the front bearing bracket *u*.

Fig. 327.—Sturtevant Eight-Pole Motor,—Pedestal Type.

1003. For what kind of service is the eight-pole motor shown in Fig. 327 chiefly used?

For driving large machine tools, blowers and exhausters to which it is direct-connected. This motor is shunt-wound and made in sizes up to 225 horse-power, running at 300 to 900 revolutions per minute.

1004. Describe the principal parts of the motor in Fig. 327 which differ from those in the motor shown in Fig. 325.

There are no end brackets, the shaft bearings being sup-

ported in pedestals *m* and *c*, Fig. 328, which, with the magnet frame *r*, are bolted to a substantial base *b*. To inwardly pro-

Fig. 328.—Magnet Frame, Pedestals and Pole Pieces of Motor in Fig. 327.

jecting bosses on the magnet frame are through-bolted the pole pieces *v* with cast-iron shoes *a* on the inner extremities.

Fig. 329.—Armature of Motor in Fig. 327.

The armature, Fig. 329, is of the slotted-drum type made from punchings of mild steel, which are coated with insulat-

ing varnish and clamped on a cast-iron spider, the hub of which is extended to support the commutator. Air is forced through and about the armature windings by ventilating ducts formed by brass space-blocks with radial arms, which

Fig. 330.—Westinghouse Motor with Belt-Tightening Pulley.

act like the blades or vanes of a centrifugal blower. A two-circuit winding is usually adopted, so that a single pair of brushes is sufficient whenever small brush capacity is required. Armature and field coils are made water-proof and oil-proof by drying and, after dipping in armalac, baking for twenty-four hours at a temperature of 100 degrees Centigrade.

1005. What is the purpose of the extra pulley shown on the motor in Fig. 330?

It is a belt-tightening attachment such as is frequently used on motors of this kind to permit setting the motor at a short distance from the driven shaft and to allow the use of a small driving pulley. The belt tightener gives a greater arc of belt contact on the driving pulley, thereby decreasing the amount of belt slip without excessive belt

tension, and it also does away with the need of a sliding base. It also takes up any jarring that would otherwise be transmitted from the driven machine to the motor armature. The motor shown is a Westinghouse constant-speed shunt machine with four poles.

1006. Explain the construction of the belt tightener.

The belt tightener consists, primarily, of a cast-iron plate *r* bolted to the motor frame, with an adjustable arm *c* carrying an idle binder pulley *p*. The arm *c* with its pulley may be adjusted and held in any position necessary to produce the required binding effect on the belt *b* by means of the adjustable spiral spring *t*.

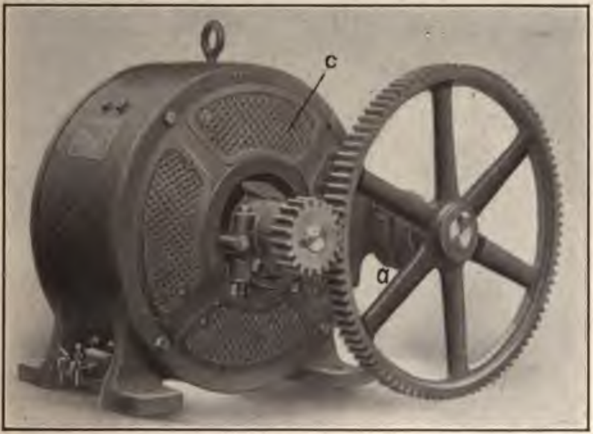

Fig. 331.—Westinghouse Semi-Enclosed Motor with Back Gears.

1007. What kind of motor is that shown in Fig. 331?

A back-geared direct-current Westinghouse motor of the semi-enclosed type designed for driving machine tools or other slow-speed apparatus. The object in using the gears and countershaft *a* is to get a considerable reduction in speed with rigid drive or with minimum floor space. Aside from the perforated end covers *c*, etc., which protect the working parts from injury, the general design and construction of

the motor is practically the same as that of the machine shown in Fig. 330.

1008. Cannot the working parts of a motor be entirely enclosed?

Yes; a Fort Wayne shunt-wound motor thus protected is shown in Fig. 332. By means of the commutator end bonnet *b* which is bolted to the frame, dust, grit and foreign matter are entirely prevented from reaching the commutator, etc. Through the hand hole at *e* which is provided with a cover, free access is afforded to all parts of the commutator

Fig. 332.—Totally Enclosed Motor made by the Fort Wayne Electric Works.

and brush rigging. The leads to the brushes and field magnet coils are shown at *m* entering the motor through a tight-fitting hole in the bonnet *b*.

Totally enclosed motors operate at higher temperatures than open motors and with somewhat reduced output, but are desirable in connection with certain kinds of work where the surrounding air is laden with foreign particles that would interfere with good commutation.

1009. What kind of motors are those shown in Figs. 333 and 334?

These are vertical direct-current Fort Wayne motors for special application under conditions which make the ordinary

horizontal-shaft motors impracticable. The motor in Fig. 333 is for belted connection, the pulley being located at *m;* the motor in Fig. 334 is for direct connection, the coupling being mounted on the shaft *t*. Both are shunt-wound machines.

The bearings are supplied with oil through the centrifugal

Fig. 333.—Fort Wayne Vertical Motor of Belted Type.

Fig. 334.—Vertical Motor of Direct-Connected Type.

force of the revolving shaft. As shown in the sectional view, Fig. 335, the oil guides flare out at the top, so that a component of the centrifugal force acts along this flaring oil duct and maintains a steady flow of oil from the large reservoir at the bottom, up through the ducts along the shaft, and back to the reservoir by gravity.

The type of brush holder used on Fort Wayne motors is shown separately in Fig. 336. A copper connection *c* is bolted and soldered to the back of the brush *v* and into

this connection is soldered a flexible cable *e* which is connected to the brush-holder body as shown, shunting the current around the brush box *t* and eliminating the variable contact between brush and box from the working circuit of the machine. The brush pressure on the commutator is

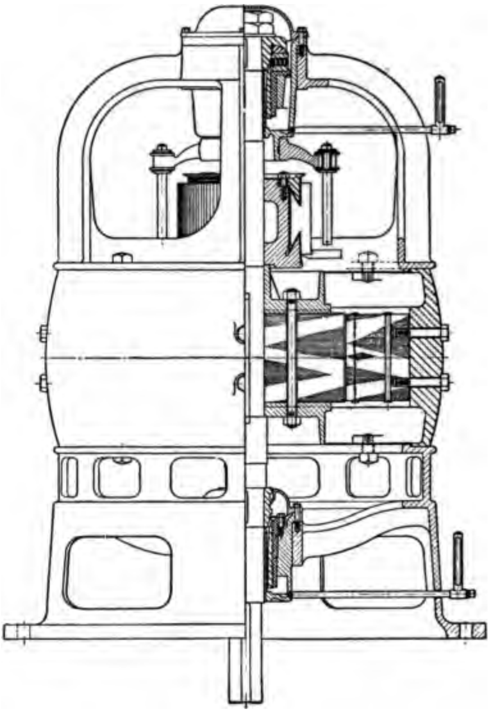

Fig. 335.—Enlarged Section of Fort Wayne Vertical Motor in Fig. 334.

maintained by the use of a flat phosphor-bronze spring *i*, the tension of which is adjusted by a self-locking thumbscrew *h* working on a threaded post or cap screw *p* attached to the brush-holder body. This threaded post or cap screw also serves as a tightening screw which clamps the brush-holder body firmly on the brush-holder stud.

1010. Illustrate and describe a series-wound motor.

A Crocker-Wheeler series-wound motor of four-pole enclosed construction is shown in Fig. 337, and the same type of motor is shown open in Fig. 338. The field coils *m, n,* etc.,

Fig. 336.—Brush Holder used on Motors shown in Figs. 332, 333 and 334.

are held in place by heavy metal flanges *c, e,* etc., independent of the pole pieces which are bolted to the frame.

The top half of the frame can be removed as shown in

Fig. 337.—Crocker-Wheeler Series Motor.

Fig. 338 without disturbing the armature *a*. The frame is of steel, octagonal in shape, with a large hand hole *H,* Fig. 337, at each brush-holder stud. There are only two sets of brushes, *b* and *d,* Fig. 338, and the brush holders are of

rugged construction to withstand heavy jars and vibration, the motor throughout being designed for severe and trying duty such as driving rolling mills and similar machinery.

Fig. 338.—Series Motor with Top Half lifted Off.

An extension is provided at each end of the armature shaft so that a pinion can be used at either end and a brake at the other. The bearings are of the ring oiling type, each

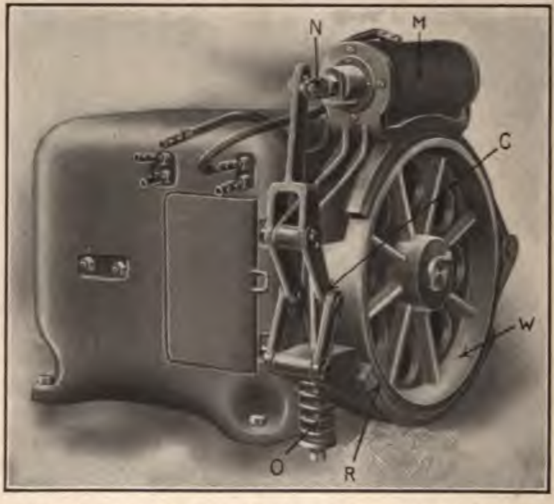

Fig. 339.—Crocker-Wheeler Series Motor with Solenoid Brake.

having a large oil ring *i* suitably placed in grooves to distribute oil over the surface of the bearings when the armature shaft revolves.

1011. Show a series-wound motor equipped with a brake.

Fig. 339 is a series-wound Crocker-Wheeler motor equipped with a solenoid electric brake for operating crane hoists where it is necessary to stop quickly. The solenoid is shown at *M* and comprises a coil of heavy wire which, when excited with the main current of the motor, attracts an iron plunger *N* into it, and through a system of levers *C* forces the brake shoe *R* out of contact with the shaft or drum wheel *W*. When

Fig. 340.—Commutating Pole Motor made by the Crocker-Wheeler Company.

the solenoid magnet is not excited, the action of the spiral spring *O* maintains a strong pressure of the brake shoe on the drum. The arrangement is such that while there is a strong force acting to hold the shoe against the drum and a strong pull is necessary to release it, a very small effort is necessary to hold the brake open.

1012. Illustrate and describe a compound-wound motor.

A compound-wound motor in which the series-field coils are placed on pole pieces separate from those containing the shunt-field coils, is shown in Fig. 340. This Crocker-

Wheeler machine is called a commutating pole motor, the commutating poles being the series ones referred to above,

Fig. 341.—Magnet Frame of Commutating Pole Motor in Fig. 340.

and which are clearly shown at *C*, *S*, etc., in Fig. 341, midway between the six shunt poles *A*, *E*, etc.

The effect of the commutating poles is to produce a sup-

Fig. 342.—Bipolar Motor made by the Crocker-Wheeler Company.

plementary magnetic field of sufficient strength to counteract the disturbing influence of that magnetic field which is set

up by the current in the windings of the armature. They also supply sufficient magnetism to commutate the current, being wound with heavy wire connected in series with the armature. As the strength of the field created by the commutating poles is therefore proportional to the load current, the motor should operate without sparking from no load to a heavy overload without shifting the brushes.

1013. Are bipolar direct-current motors manufactured?

Yes; but mostly in sizes below 7½ horse-power. For higher power, multipolar construction is followed.

1014. Illustrate and describe a bipolar motor.

A Crocker-Wheeler shunt motor of this type is shown in Fig. 342. It is made in nine sizes from 1/16 to 7½ horse-

1. Magnet Frame.
2. Front Bearing Bracket.
3. Rear Bearing Bracket.
4. Pole Shoes.
5. Pole Shoe Screws.
6. Field Coils.
7. Porcelain Bushings.
8. Armature. (Includes 9 and 10.)
9. Commutator.
10. Shaft.
11. Pulley Key.
12. Rear Bearing Bracket Cap Screws.
13. Front Bearing Bracket Cap Screws, with Washers.
14. Front Journal Box with Oil Ring.
15. Rear Journal Box with Oil Ring.
16. Journal Box Cap Screw.
17. Oil Well Plugs.
18. } Brush Holders.
18. }
19. Brush and Terminal Studs.
20. Brass Washers for Brush and Terminal Studs.
21. Brush and Terminal Stud Nuts.
22. Brushes.
23. Name Plate.
24. Name Plate Pins.
25. Pulley.

Fig. 343.—Exploded View of Motor in Fig. 342.

power and for operation on 115, 230, or, in all except the two smallest sizes, on 500-volt circuits.

Referring to Fig. 343, which shows the various parts sep-

arately, the poles are cast solid with the frame and the pole-shoes are laminated. The latter are fastened to the poles by screws, holding the field coils in place. The armature core is also laminated and keyed directly to the shaft. The arma-

Fig. 344.—Paper Pulley for Small Motors.

ture coils are formed, taped, varnished and baked before inserted in the insulated slots on the periphery of the core. The brush studs pass through the front bearing bracket but

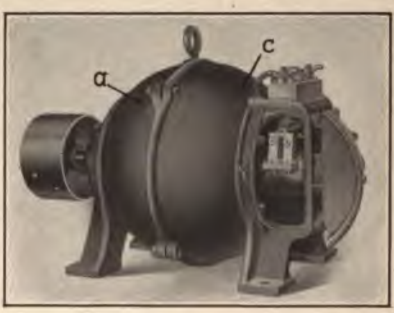

Fig. 345.—Small Round Type Motor built by the Sprague Electric Works.

are insulated therefrom by porcelain bushings which are held in place by type metal applied in molten form. Nuts are provided on the projecting ends of the brush studs, making them serve the purpose of terminals as well.

1015. Are not paper pulleys sometimes used on small motors?

Yes; the General Electric Company uses them entirely on their small belted direct-current motors up to ¼ horse-power. One of their paper pulleys is shown in Fig. 344. They claim for it a high coefficient of friction and practically no slip, thereby reducing belt tension and lowering the first cost and maintenance expense of both the belting and the mechanical transmission. Paper pulleys are, of course, lighter in weight than metal ones and, as a rule, are more accurately balanced.

Fig. 346.—Half Yoke and Pole Piece of Motor in Fig. 345.

1016. In what respect does the motor in Fig. 345 differ from other direct-current motors?

Chiefly in its field-magnet construction. Only one field-magnet coil is used to energize the poles.

1017. Describe the peculiarities of construction of the motor in Fig. 345.

Its field-magnet frame consists of two steel castings *a* and *c*, each casting being approximately a hemispherical shell, provided with an internally projecting oblique magnet pole, as shown in Fig. 346 at *n*. The two halves of the magnet frame when bolted together completely enclose and protect the single magnet coil, which embraces and magnetizes both the oblique poles. The construction of the brush holder is

clearly shown in Fig. 347. This machine is built by the Sprague Electric Works.

1018. In what form are Sprague motors of larger size built?

As shown in Fig. 348. The frame consists of a cylindrical

Fig. 347.—Brush Holder and Armature of Motor in Fig. 345.

yoke *m*, Fig. 349, to the inner side of which the poles *n*, *s*, etc., are bolted, each pole carrying a magnet coil *r*. Cast steel is used for the yoke in the smaller sizes and cast iron

Fig. 348.—Six-Pole Motor made by the Sprague Electric Works.

for the larger sizes. Cast-iron brackets *b*, which contain the bearings, are bolted to each end of the yoke, the front bracket carrying the brush rocker arm.

The brush holders, shown separately in Fig. 350, are of the box type in which the carbon brushes slide and are pressed against the surface of the commutator by flat, adjustable spiral springs *u*. A flexible copper lead *i* electrically

Fig. 349.—Yoke and Magnet Poles of Motor in Fig. 348.

connects each brush with its holder. The cast-iron rocker arm that carries the insulated studs upon which the brush holders are mounted, is supported on a machined seat on the inside

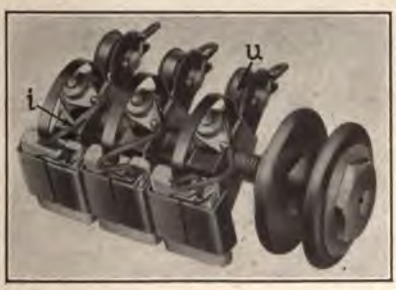

Fig. 350.—Brush Holder Stud and Brushes of Motor in Fig. 348.

of the front bearing bracket. The brush holders are adjustable along the studs, parallel to the shaft.

1019. Show a motor adapted for the operation of very large machinery.

The 250-horse-power three-bearing motor in Fig. 351 is

adapted for heavy work of this nature or for furnishing the entire motive power in a large manufacturing establishment. It is a Western Electric compound-wound machine of interpole construction for 115, 230, or 550-volt circuits and runs at slow or moderate speed.

Each brush-holder stud carries five brushes, and their position around the commutator is adjusted by turning the handwheel *w*, the shaft of which gears into the rocker arm. The bearings are self-alining and self-oiling, and are supported

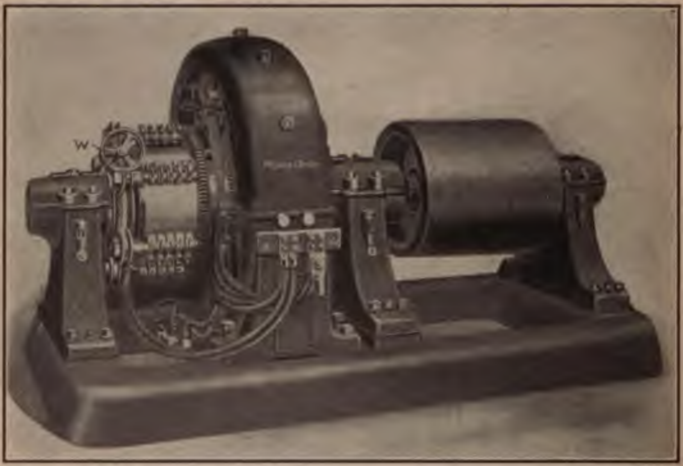

Fig. 351.—Western Electric Direct-Current Motor for driving Heavy Loads.

as shown, upon pedestals of heavy construction to prevent vibration and noise.

Full load is carried continuously with a temperature rise not exceeding 40 degrees Centigrade on the windings and 45 degrees Centigrade on the commutator. An overload of 25 per cent. may be carried for two hours, with a maximum temperature rise of not over 60 degrees Centigrade on the commutator and 55 degrees Centigrade on the armature and field. Fifty per cent. overload may be carried momentarily without injurious heating or sparking.

ALTERNATING-CURRENT MOTORS

PRINCIPLES GOVERNING THEIR ACTION

1020. How does an alternating-current motor differ in construction from a direct-current motor?

The chief difference between them is the absence of a commutator in the synchronous alternating-current motor.

1021. Explain how an alternating-current motor operates without a commutator.

A commutator is used on a direct-current generator to convert the alternating current developed in the armature winding into direct current, and in a direct-current motor to change the direct current again into alternating current for use in the armature. Suppose, now, the armature windings of a direct-current generator and of a direct-current motor be connected together with their commutators omitted. Apparently, the same conditions would exist as with the use of the commutators, but that is not entirely true. The motor would run satisfactorily only when the alternating impulses from the generator caught the armature coils of the motor systematically in the same positions in which reversal would be accomplished by a commutator. Consequently, for a certain speed of the generator the impulses will be efficient only when the armature of the motor is revolving at such a speed that each coil passes its proper reversal point simultaneously with each reversal of the generator current. With the same number of poles on both generator and motor, this condition will be satisfied only when both are running at exactly the same speed, at which time they are said to be " in step " or " in synchronism "; hence a motor so operating is called a " synchronous " motor.

1022. If the number of poles on the motor is not the same as on the generator, will the motor operate satisfactorily?

Yes; when the speed of the motor is such as to satisfy certain conditions.

1023. What conditions are referred to in Answer 1022?

The number of field-magnet poles on the motor, multiplied by the speed of the armature in revolutions per minute, must be equal to the number of poles on the generator multiplied by the speed of its armature in revolutions per minute. For example, if an 8-pole generator, running at 1200 revolutions per minute, supplies current to a 6-pole motor, the motor must run at $8 \times 1200 \div 6 = 1600$ revolutions per minute.

1024. Is the speed of a synchronous motor expressed in other terms than the speed of the generator and the number of poles on the machine?

Yes; but the speed and poles of the generator determine the matter after all. The speed of the motor in revolutions per second is numerically equal to the frequency of the supply current divided by half the number of poles on the motor. Representing the frequency in cycles per second by f, and the number of field-magnet poles by p,

$$\frac{2f}{p} = \textit{speed of motor in revolutions per second.}$$

The frequency, however, is equal to half the number of poles on the generator multiplied by the revolutions of its armature per second.

1025. Are there any disadvantages inherent in the synchronous motor?

The synchronous motor possesses several disadvantages, one of which is its inability to start from rest without additional assistance. It is usual, therefore, to start a synchronous motor unloaded or very lightly loaded by some means so that its speed is such that it will be in step with the generator supplying it, before closing the circuit between them.

1026. What other disadvantage has a synchronous motor?

A second disadvantage is that its field strength must bear a definite relation to the load. So long as the load is no greater than the torque of the motor is sufficient to pull, the motor, after being properly started, will continue to run at synchronous speed. However, the moment the drag due to the load exceeds that exerted between the magnet poles and the armature, the speed will decrease and the motor will drop out of "step."

1027. What should be done when a synchronous motor is out of step?

The motor should be cut off from the supply circuit at once and the load removed until the motor has been started again.

1028. For what purposes is a synchronous motor best adapted?

For work where there is a constant load to be driven at a uniform speed. For all purposes where 100 horse-power or more is required continuously for many hours at a time, as for example in pumping stations, the synchronous motor is very useful.

1029. What are the advantages of the synchronous motor?

It can be adjusted to be practically non-inductive in operation, or to act like a condenser of large capacity, causing the current to lead the impressed electromotive force and thereby compensating the inductance in the circuit and improving the power factor; when supplied with current at constant frequency and proper voltage, it maintains actually constant speed unless subjected to an excessive load.

1030. What are the principal features of difference between the operating conditions of a synchronous motor and those of a direct-current motor?

The field magnet of a synchronous motor is separately

excited and therefore can be kept constant regardless of changes of load. When the load increases, more current is necessary in the armature to keep up the output, but if the frequency remains constant the counter-electromotive force of the motor cannot be decreased by decreasing the speed, as is the case with a direct-current motor; the speed is strictly constant. The increase in current is obtained by the automatic shifting of the phase relation between the motor and the alternator supplying it. Under light loads the counter-electromotive force of the motor is nearly opposite in phase to that of the impressed electromotive force, and but little current flows through the armature of the motor; as the load increases, it momentarily retards the armature until its counter-electromotive force becomes shifted in phase far enough from exact opposition to the impressed electromotive force to allow sufficient increase in the current through the motor to pull the additional load. When this condition is attained there is not any further tendency for the armature to slip, and it will remain in exact synchronism with the generator, but with the armature lagging behind the position of exact phase opposition at any instant of time.

1031. **What would happen if a synchronous motor were heavily overloaded?**

Its armature would be dragged further and further behind the phase of the impressed electromotive force until it finally fell out of step; then it would stop running.

1032. **Is there any other type of alternating-current motor besides a synchronous motor?**

Yes; the principal other type is the induction motor.

1033. **What are the distinguishing features of the induction motor?**

An induction motor differs from a synchronous motor in the construction of its field magnet or stator, in not requiring separate field excitation and in having its armature current induced in the conductors instead of being supplied directly from an external circuit.

1034. What are the features of construction of an induction motor?

The induction motor consists principally of two parts, one stationary, the other movable. The former is usually the primary or " field " member, composed of a laminated iron core carrying a winding very similar to that on the armature of an alternating-current generator. The moving part is the secondary or armature member, consisting of a laminated iron core carrying heavy conductors which lie in longitudinal slots and are connected together at the ends with copper

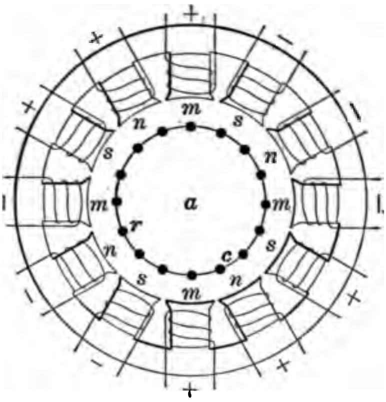

Fig. 352.—Diagram illustrating the Principles of Operation of Induction Motors.

rings securely riveted and soldered in place. The primary circuit is supplied with alternating current, and this induces currents in the armature conductors, which currents react on the magnetic field set up by the primary winding and thereby cause rotation of the armature.

1035. Illustrate the principle of operation of the induction motor by means of a diagram.

Referring to Fig. 352, which shows a 12-pole field magnet wound so as to produce three sets of four poles each, it will be evident that if each set of coils, *s*, *n* and *m*, be supplied from one phase of a three-phase circuit, the poles *m m m m*

of the polarities shown resulting from one phase, would be immediately followed in point of time by the poles *n n n n* of the same respective polarities resulting from the next phase, and these by the poles *s s s s* from the third phase. There would result, therefore, a rotation of the axis of the magnetic field, producing what is commonly termed a rotary field.

The armature *a*, sometimes called the rotor, consists of a large number of uninsulated copper bars *r*, running lengthwise through the periphery of the armature core and electrically connected to each other at each end by a copper ring *c*. The currents induced in these armature conductors by any one set of poles bear such relation to the poles produced by the next phase as to develop an effective torque, and the armature *a* will consequently start from rest with considerable torque and quickly speed up under the magnetic attraction exerted upon it.

1036. If the field winding be supplied with single-phase current, will the armature rotate?

Not unless it is started up by some outside force; this is due to the fact that a single-phase current will not produce a rotary field while the armature is at rest. After it is brought up to normal speed, the magnetic field set up by the armature conductors reacts on the magnetic field of the stator to produce a rotary resultant field.

1037. Has the type of armature shown in Fig. 352 any special name?

It is called a "squirrel-cage" rotor on account of its mechanical construction.

1038. Can induction motors be operated with any other kind of armature?

Yes; there is another kind which is wound somewhat like the field or stator coils, but with insulated copper conductors of relatively large size. If the motor has to start with a heavy load, as in the case of elevator and hoist motors, this

winding is preferable. By carrying the armature terminals out to slip rings and using brushes on them, an external non-inductive starting resistance can be used.

1039. **What is gained by using a non-inductive starting resistance?**

It gives the motor a high torque with a comparatively small starting current, making it possible to start the motor at full load running torque with an armature current not much in excess of that required at full speed. This it does by advancing the phase of the armature current so that it is in a better instantaneous position with respect to the stator poles.

1040. **Cannot motors with squirrel-cage armatures be made to start with considerable torque?**

They can, but they require much greater starting current than those of the other kind.

1041. **How may the speed of the rotating field be calculated?**

The speed of the rotating field in revolutions per second is equal to the frequency of the supply current in cycles per second, divided by one-half the number of magnetic poles produced by each phase of the supply current. Thus, in a three-phase four-pole motor, there would be four magnetic-field " poles " produced by the current in each phase, and if the supply current had a frequency of 60 cycles per second, the speed of the rotating field would be $60 \div 2 = 30$ revolutions per second. The speed of the armature is more or less below the speed of the rotating field.

1042. **Can the speed of the armature ever become equal to that of the rotating field?**

No; in order that the electromotive force induced in the armature conductors may be sufficient for the resulting current to produce the required torque for rotation, the armature must always run below synchronous speed; that is, the speed of the armature must be less than that of the rotating

field. The difference between these two speeds, expressed as a percentage of the speed of the rotating field, is called the " slip " of the motor.

1043. What determines the amount of slip in an induction motor?

The load. As the load on the motor increases the slip increases, and as the load on the motor diminishes so also does the slip. It is evident, however, that the value of the slip can never become zero on account of the friction of the bearings, etc., but at no load it is so small that the speed of the armature is usually taken as equal to that of the rotating field. At full load the slip is such that the armature speed is from 2 to 10 per cent. less than the speed of the rotating field, according to the size of the motor.

1044. How does an induction motor operate under varying loads?

Very much like a direct-current shunt-wound motor. In both, the armature current and torque depend upon an impressed and a counter-electromotive force; in the direct-current motor the impressed electromotive force is supplied from the line wires through brushes, while in the induction motor it is induced by the current in the field winding. The speed of both types varies inversely as the load varies. In the induction motor the torque varies as the square of the applied voltage, while the torque of the shunt-wound motor is practically independent of the applied voltage. On the other hand, the speed of the induction motor is not affected directly by variations in the applied voltage, while that of the direct-current motor is controlled by the applied voltage.

1045. What methods are employed for controlling the speed of an induction motor?

The speed may be controlled in three ways: By varying the impressed electromotive force, by varying the armature resistance or by changing the connections of the field winding. In the last method the speed is increased by changing the winding so as to increase the number of poles and is de-

creased by changing the winding so as to decrease the number of poles. The use of the second method requires a specially wound armature, but this method provides the most efficient means of varying the speed. The first method is a decidedly inefficient one and is inferior to the other two methods because it controls the speed by affecting the torque of the motor.

1046. How is the direction of rotation reversed?

By reversing the direction of the current through *one branch* of the field winding. This is easily done by reversing any two of the supply wires connected to the field winding.

1047. Is the rotating field always produced by the stationary member of an induction motor?

Not necessarily. The revolving member may be made the primary, using collector rings and brushes to connect it with the line, and the short-circuited armature winding would then be on the stationary member. The rotating field would tend to draw the short-circuited member around after it, but as that member would be held stationary, the moving member would be pulled around in a direction opposite to that in which the magnetic field would rotate. Such a motor would have no important advantage and the serious disadvantages of moving contacts and revolving high-voltage windings.

1048. What are the disadvantages of the induction motor?

The greatest disadvantage is its low power factor, which entails a larger current for a given voltage and output than other motors. This in turn causes a greater loss in the lines and necessitates greater station capacity. Furthermore, the lagging current taken by an induction motor makes difficult the regulation of voltage on the circuit.

1049. In what respects does a single-phase induction motor differ from a polyphase induction motor?

The outward appearance is about the same and the principles of construction are identical. The single-phase motor

has a somewhat lower efficiency and power factor, and when running with no load, a single-phase motor takes considerably more current than a polyphase motor.

1050. What method of starting is used with single-phase motors?

A device frequently used consists of an inductive coil or a condenser in series with a special starting winding on the motor. This arrangement causes the current in the special winding to be out of phase with the current in the regular winding, converting the machine temporarily into an unsym-

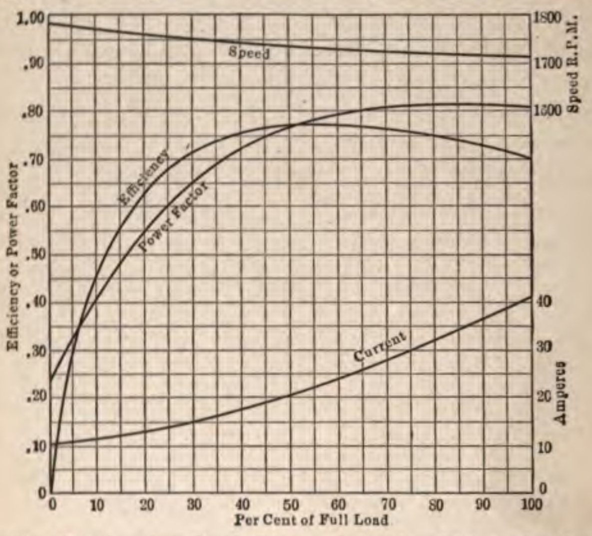

Fig. 353.—Curves of a Single-Phase Induction Motor, showing Average Values of Efficiency, Power Factor, Speed and Current at Different Loads.

metrical sort of two-phase motor having sufficient torque to start the armature without load.

1051. What are average values for the efficiency, power factor, speed and current at different loads of a small single-phase induction motor?

A general idea of these values may be obtained from the four curves in Fig. 353, which were plotted from a test of a

3-horse-power 114-volt single-phase induction motor. The scale along the base line represents percentages of full load; the vertical scale at the left gives the values of efficiency and of power factor; and the vertical scale at the right refers to speed in revolutions per minute and current in amperes, the former near the top and the latter near the bottom of the diagram. Reference to the diagram shows that at half load (50 per cent. of full load) the speed was 1740 revolutions per minute, the efficiency 77.5 per cent., the power factor 77 per cent. and the current 21 amperes. At full load (100 per cent.) these values were 1720, 70, 81 and 41.5 respectively.

1052. **Can the full-load current of an induction motor be calculated?**

It can if the voltage, power factor and efficiency of the motor are known. If $I =$ full-load current per wire, $H.P. =$ horse-power of motor, $E =$ voltage at the motor terminals, $p =$ power factor and $e =$ efficiency, then for a single-phase motor

$$I = \frac{746 \times H.P.}{E p e};$$

for a two-phase motor

$$I = \frac{373 \times H.P.}{E p e};$$

and for a three-phase motor

$$I = \frac{430.7 \times H.P.}{E p e}.$$

SELECTION

1053. **What general considerations should govern the selection of a motor?**

Its material and workmanship should be of the best quality, solid and durable. The various parts should be of ample size for the work assigned to them, as otherwise the machine will be inefficient and will require frequent repairs. A machine with a good finish is very seldom poorly constructed, and it is also much easier to keep clean and attractive. As far as

possible the various parts of the motor should be plain, simple and interchangeable; complicated parts, unless they have already been tried out and have proved their standard worth, should be viewed with suspicion. The connectors and other small parts should be arranged so they cannot readily become loose and normally exposed to injury.

1054. How about the form and weight of a motor?

The motor should be symmetrical; that is, the parts should not project abnormally so as to give the machine an awkward appearance. A very high or very flat machine is both awkward in appearance and clumsy to handle, and is therefore undesirable. To afford stability, the large and heavy parts should be as low as possible. If the shaft is high above the base, there will be considerable vibration which, of course, is objectionable, yet it must not be so low as not to afford sufficient room for the proper operation of the belt, or other attachment. A low shaft on a horizontally belted machine is liable to cause trouble by reason of the belt striking the floor. The weight of a motor for stationary use should be sufficient to secure stability. Freedom from vibration, steadiness of operation, strength and durability are largely dependent upon ample weight.

1055. What special features regarding the revolving member are worthy of notice?

It should turn easily in its bearings and be perfectly balanced. If it is not well balanced there will be a noticeable vibration of the machine when running at full speed. The end play or movement lengthwise of the shaft in the bearings should be from 1/16 to $\frac{1}{8}$ inch, and there should be at least $\frac{1}{8}$ inch between the surfaces of the revolving and stationary members. The peripheral speed of the revolving part, that is, the speed at its circumference, should not ordinarily exceed 3000 feet per minute.

1056. How is the peripheral speed estimated?

By measuring the circumference of the revolving member

in feet and multiplying it by the speed of this part in revolutions per minute.

1057. What special features regarding the frame are worthy of notice?

The frame should be designed so as to afford easy access to the windings within it. To facilitate moving or lifting the motor, there should be an eye-bolt screwed into the top of the frame.

1058. Should a motor be chosen with a large or small margin of capacity?

It is advisable for a motor to have a considerable margin of capacity in view of future requirements. As the motor consumes power only in proportion to the work it is doing, there is practically no disadvantage, except the slight additional first cost, of having the capacity of a motor 2 or 3 per cent. greater than that actually required at the beginning.

INSTALLATION

1059. What consideration should govern the location of an induction motor?

It should be placed where it is easily accessible for inspection, oiling, cleaning and repairs. It must not be exposed to moisture, leaky steam pipes or dirt and coal dust. It should receive proper ventilation and should be mounted so that there is sufficient distance between its pulley and the pulley on the machine driven by it to permit the belt to drive efficiently and without excessive tension.

1060. What kind of foundation is most desirable?

A heavy timber or a concrete foundation is best. It should be sufficiently heavy and so well bonded that there will not be vibrations when the machine is running. The foundation of the motor and of the driven machine should set with respect to each other so that the two shafts are parallel, in order that the rotor or rotating parts of the induction motor may "float" in the bearings.

1061. In lining up a belted induction motor with the driven pulley, what special precautions should be observed?

The position of the motor with respect to the driven machine should be such that the belt will be tight enough to run without slipping, but not so tight that the bearings become unduly heated. The crowns of the two pulleys should be as nearly as possible alike to prevent the belt from wabbling; the greatest diameter should be at the center of the pulleys so that the belt will travel true and allow the rotor shaft to float. The belt must be free from grease and dirt, else it is likely to slip and flap, and the edges of the belt must stretch equally or there will be an objectionable sidewise movement of the belt on the pulleys.

1062. In alining a direct-connected induction motor, what special precautions should be observed?

The shafts of the machines to be coupled must be in perfect alinement with each other, and this alinement must be maintained by building the foundations so that they will not settle or vibrate.

1063. If the motor is to be geared to its load, what points should be considered?

The shafts must be carefully adjusted to parallelism and set the specified distance apart. The pinion should fit securely on the motor shaft, but not so tightly that it cannot be forced on or off with moderate pressure. If the pinion is driven on by heavy blows with a ram or sledge, the rotor conductors are liable to be jarred out of place and suffer damage.

1064. If it is desired to use the motor in other than an upright position, what changes are necessary?

Ordinarily, induction motors are made so that the only change necessary for operating them in other than an upright position is the shifting of the bearing brackets either 90 degrees or 180 degrees as the case may be, in order that the oil wells shall remain in their proper position.

1065. Are there any special precautions to be observed when shifting the bearing brackets?

Care must be taken to replace them so that the rotor is properly centered. The air gap between the rotor and the pole faces must be the same at all points.

1066. In assembling an induction motor just received from the factory, what points should be given special attention?

The bearings and oil wells must be carefully wiped clean and the shaft rubbed with oil before being put into place. Only the highest grade of dynamo oil should be used in the bearings and they must be filled to such a height that the surface of the oil comes above the lowest edges of the oil rings. The oil rings must revolve freely and carry sufficient oil to flood the bearings.

1067. In wiring up an induction motor, how is one to know what size conductor to use?

The size of conductor to use is, of course, determined by the amount of current the motor requires. The full-load current for an induction motor is usually stamped on the name-plate. When it is not there, the builder should be asked to specify it.

1068. What should be the capacity of the conductors and fuses in the motor circuit with respect to the full-load motor current?

For ordinary service the conductors and fuses should have a capacity $1\frac{1}{2}$ times the full-load current. Where elevators or hoists are operated by the motors or wherever heavy starting duty is required of them, the capacity of the fuses should be $2\frac{1}{2}$ times the full-load current.

1069. What size of conductor would be necessary for wiring up a two-phase induction motor, requiring 43 amperes, for ordinary service?

The capacity of the conductor, according to Answer 1068, should be $1\frac{1}{2} \times 43$ amperes $= 64.5$ amperes. Referring to

the table on page 20, showing the carrying capacities of copper wires, it will be found that a No. 4 B. & S. gage rubber-insulated conductor is the smallest size that will safely carry this current.

1070. What size fuse should be employed in a three-phase motor circuit if the motor requires 13 amperes at full load and is to be used as a hoist?

According to Answer 1068, the fuses should be rated at $2\frac{1}{2}$ times 13 amperes; that is, they should be capable of carrying $2.50 \times 13 = 32.5$ amperes, without melting. Referring to Answers 689 and 695, a ribbon form of fuse rated for 35 amperes in either the open or enclosed ferrule contact form would answer the purpose.

OPERATION

1071. Are the starting conditions of different induction motors about the same?

No, they differ widely. Some start with full-load current and full-load torque, while others require two or more times their full-load current in starting under similar conditions. Two-phase and three-phase induction motors start with a higher torque and lower current than do single-phase induction motors.

1072. What is objectionable about a large starting current?

It is highly inductive and has very bad effects on the regulation of the supply circuit.

1073. In the operation of an induction motor, how may the starting current be kept down?

By inserting resistance in the rotor circuit at the time of starting or by starting the motor on a voltage lower than the normal line voltage.

1074. Is extra resistance necessary in starting an induction motor?

It is necessary with all single-phase motors and with poly-

phase motors required to start under considerable load. Small polyphase motors and large ones not required to start under load can be started by simply closing the main-line switch; in these, the simple " squirrel-cage " form of rotor winding is sufficient. In the others it is necessary to modify the " squirrel-cage " type as explained in Answer 1038 to permit the use of a starting resistance.

1075. Explain the resemblance between the starting conditions of an induction motor and those of a shunt-wound direct-current motor when starting resistance is used.

These types of motor behave very much alike. If the field and armature of a shunt-wound motor are both switched on the supply circuit at once, the armature, on account of its comparatively low resistance, takes a relatively large starting current and its magnetic reaction against the field cuts down the starting torque. The large starting current is, of course, lowered, and the torque is increased as soon as the armature speeds up, but if, as is customary, a resistance is inserted in the armature circuit at the time of starting, the results are much more satisfactory. So in the case of an induction motor a resistance inserted in the rotor or armature circuit at the beginning enables the motor to receive its magnetizing current and start with a good high torque. As the motor speeds up, the starting resistance in the rotor or armature circuit is cut out, as in the case of a shunt-wound motor.

1076. How is the operation of the starting resistance made easy in many modern types of induction motor?

By having the starting resistance mounted within the rotor. As the rotor speeds up after starting, a sliding collar on the shaft, actuated by means of a hand lever, cuts out the starting resistance and short-circuits the rotor circuit.

1077. What other common forms of starting device are used?

In some induction motors the starting resistance is separate from the machine and is introduced in the armature

circuit through brushes pressing upon contact rings to which the rotor winding is connected. A multiple-pole double-throw switch is wired in this circuit and is closed in one direction to start and then thrown in the opposite direction after the armature has reached its normal speed. This switch is usually marked " Starting " and " Running " to designate the two operating positions.

There is also an " oil-immersed " type of starting device

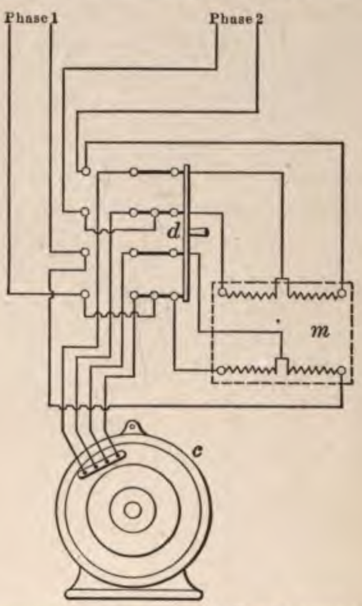

Fig. 354.—Arrangement for Starting a Two-Phase Induction Motor at Low Voltage.

which comprises a hand-wheel or lever controlling a revolving type of switch which makes the required connections in proper sequence. The various positions of the switch are shown by an index plate which indicates the " starting," " running " and " stop " positions. The hand-wheel or lever of this switch should be moved slowly from the " starting " to the " running " position to allow the armature gradually

to reach normal speed without an excessive rush of current through the machine. The switch should always be left either on the " running " or the " stop " position.

1078. Is any special arrangement necessary for starting an induction motor on a lower voltage than normal?

Step-down transformers are used for this purpose. For a two-phase motor they are connected as shown in Fig. 354. In starting, the four-pole switch *d* is closed on the right-hand contacts, which introduces the two step-down transformers at

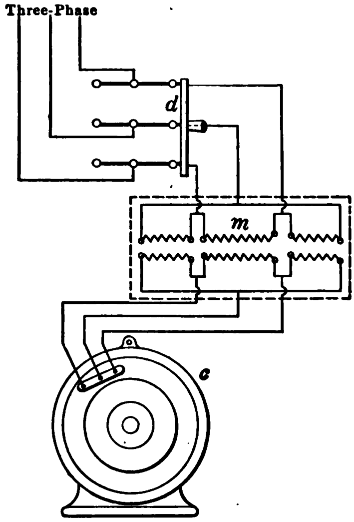

Fig. 355.—Arrangement for Starting a Three-Phase Induction Motor at Low Voltage.

m in circuit. When the motor *c* is up to speed, the switch *d* is closed on the left-hand contacts. This cuts out the step-down transformers and applies the line voltage directly to the motor.

1079. How should the step-down transformers be connected for starting a three-phase motor?

It is advisable to use three transformers connected in " mesh " through a three-pole switch, as represented in Fig. 355. As in the previous case *d* represents the switch, *m* the

transformers and *c* the motor. If one transformer breaks down, it may be cut entirely out of circuit and the motor operated at a reduced load on the remaining two while the injured one is being repaired. In this case, the voltage of each transformer should be the same as the voltage from wire to wire of the line.

It is possible to carry the full load of the motor on only two transformers, but in this case the capacity of each transformer must be 173 per cent. of the capacity of each of the three transformers when three are used; hence there is no great saving, if any, in first cost, and the certainty of a complete shutdown if one transformer fails to work properly.

1080. What should be the capacity of the step-down transformers with respect to that of the induction motor?

The total capacity of the transformers, in kilowatts, should equal the horse-power capacity of the motor.

1081. When is the resistance method of starting induction motors preferred to the low-voltage method?

Where a very large starting torque is required, as in elevator or hoisting work, the resistance method is always used. In factories where the motor starts only the shafting and the load comes on subsequently, the low-voltage method is satisfactory.

1082. Is there any other method of starting an induction motor with a good torque?

Yes, by lowering the frequency of the applied current; because with a reduced frequency there is not as great a slip at low speeds. This method is not as common as the other two because it is not always practicable to reduce the frequency received from the line. It is practicable, however, when two induction motors are used.

1083. Show a diagram which illustrates this last method applied to two induction motors.

Fig. 356 illustrates this case. The stator winding of the motor *b* is connected in series with the rotor of the motor *a*,

which consequently starts with a strong torque. The motor *b* receives its current at a reduced frequency and therefore starts also with good torque.

1084. How is one to know the kind of work that can economically be performed by an induction motor?

An induction motor works well where it can run at full speed with a load that requires to be started only occasionally.

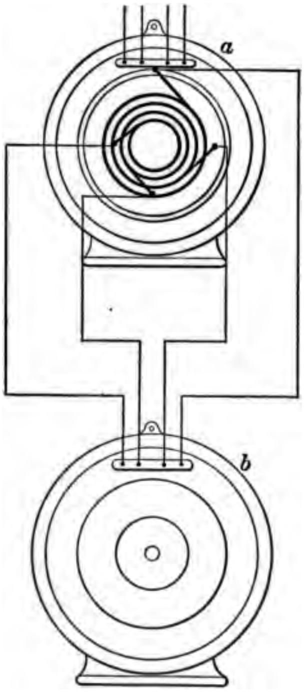

Fig. 356.—Arrangement for Starting an Induction Motor at Low Frequency.

It will usually be economical and satisfactory when applied to the same kind of work that could be done well by a direct-current shunt-wound motor. When working at or near full load and at constant speed, the efficiency and power factor of an induction motor are at their best.

1085. In what respect is an induction motor preferable to a synchronous motor?

It requires less attention.

1086. What effect does an induction motor have upon the current in the circuit on which it is running?

It causes the current in the supply circuit to lag behind the voltage and therefore impairs the power factor of that circuit.

1087. What effect does a synchronous motor have upon the current in its supply circuit?

It produces a leading current if working under a steady load and with strong field excitation. If, therefore, synchronous motors are connected to the same line with induction motors the leading currents produced by the former tend to neutralize the lagging currents produced by the latter.

1088. In starting an induction motor by the resistance method, what precaution should be observed regarding the starting resistance?

Care must be taken before closing the main switch to see that the starting resistance is not short-circuited; if the starting resistance is short-circuited, the motor will take excessive current from the line and it may not start at all.

1089. How long should the starting resistance be left in the motor circuit?

Only during the starting period. As the motor comes up to speed the resistance should be gradually cut out, and each step of the cutting-out process should be only of such duration as will permit the motor to come up to the maximum speed for that step. At the final step, the rotor winding is practically short-circuited through the brushes. The total time for starting should not exceed thirty seconds.

1090. When resistance is used for controlling the speed of an induction motor, cannot this resistance be left in the armature circuit as long as desired?

Yes, because this resistance is especially designed to carry the full current continuously.

1091. What effect upon the normal output of an induction motor has the resistance generally used for speed control?

A motor designed for 50 per cent. speed control usually has a resistance of ample capacity to reduce the speed to 50 per cent. of normal without affecting the normal full-load torque. The horse-power output of the motor at the lower speed is therefore 50 per cent. of the normal output and varies in about the same proportion for other speeds less than normal.

1092. If an induction motor fails to start, what may be the cause of the trouble?

A broken wire or faulty connection. The current fails or is shut off at the station. Excessive friction in the bearings. A blown fuse. The main switch open. A heavy overload.

1093. In case the motor stops during operation, where may the trouble usually be found?

The same defects given in Answer 1092 will cause a motor to slow down or stop during operation.

1094. What important points must be considered in the operation of induction motors in which the starting resistance is introduced in the armature circuit through contact rings and brushes?

The contact rings should be kept clean. The brushes should make proper contact with the rings when the armature is at rest and should be clear of them when the armature has reached its normal speed. New brushes should be installed as soon as there is any danger of the brush holders striking the rings, and the brushes should be sand-papered to the shape of the ring so there will be contact over their entire face. Failure to do this will cause poor contact and serious sparking, which soon pits the rings and necessitates turning them down to a smooth surface. A little sparking at the brushes and some noise when starting, however, should not occasion alarm, as this lasts but a short time and ceases when

the armature has come up to speed and the contact between rings and brushes broken.

1095. If it becomes necessary to take out the armature, what precautions should be observed in handling it?

Do not pick up the rotor with a sling, unless it has a strut or spreader, Fig. 318, to keep the rope or chain from injuring the winding. Do not take out the rotor and set it on the floor without placing a thick, heavy pad under it, or else supporting it by blocks under the shaft so that the rotor core is clear of the floor.

1096. What mechanical defects may cause trouble?

The bearings may become worn and need renewing, in which case the rotor may strike the stator core. The bearings may become scratched and roughened by grit or dirt in the oil. If any such foreign matter is seen, the bearings should be cleaned and the oil renewed. In no case should old oil be used without filtering it.

1097. What special attention should be given the starting switch or handle?

It must not be left in the "starting" position while the motor is connected to the circuit. It must be placed in the "off" position when the motor is shut down.

1098. Is water or oil injurious to the windings?

It is, and it should not be allowed to accumulate on them.

1099. What is frequently the cause of oil coming in contact with the windings?

Leaky bearings caused by the oil being too high in the bearings, the armature shaft not being level or the end plate on the bearings not being properly sealed.

TYPICAL MODERN FORMS

1100. Are all induction motors of the same general type of construction?

There are two general types of induction motors according

to the construction of the rotor: the squirrel-cage rotor type and the wound-rotor type.

1101. Which type is the simpler in construction?

The squirrel-cage type, in which the rotor consists merely of a slotted core carrying copper conductors embedded in the slots and electrically connected at the ends to heavy copper rings, one on each end of the core. In the wound-rotor type

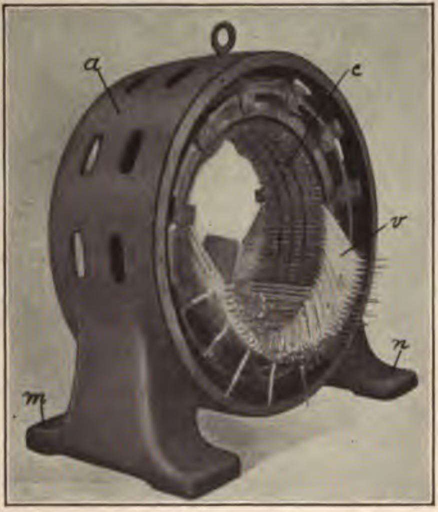

Fig. 357.—Stator of Induction Motor partially Wound.

the rotor is equipped with a winding which is connected in series with a dead resistance for starting and afterwárd short-circuited. In some motors slip rings and brushes are employed for making connection between the winding and the starting resistances; in others the resistance is mounted within the rotor and adjusted by means of a rod or lever, and in still others adjustment is obtained by shifting the brushes on the rings, which then become short-circuited.

1102. Illustrate and describe the construction of the

principal parts of the squirrel-cage and wound-rotor machines.

The stator frames of both motors are of cast iron and in one piece, as shown in Fig. 357 at *a*. The feet *m* and *n* are broad and the frame is made so that there will be no springing;

Fig. 358.—Typical Squirrel-Cage Rotor.

this is necessary in all induction motors on account of the small clearance between the stator and the rotor. The laminations, shown assembled at *c*, are of sheet steel, slotted to receive the windings. The stator windings, shown at *v*, are

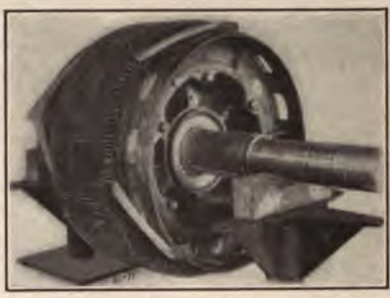
Fig. 359.—Wound Type of Rotor during Process of Winding.

wound in forms and individually insulated before being put in the slots.

The rotor of the squirrel-cage type of motor consists of a spider *n*, Fig. 358, keyed to the shaft *d* and carrying a slotted laminated core *r* something like the armature core of a direct-

current machine. The rotor conductors consist of copper bars *b* placed in the slots formed by the laminations near the periphery. End rings *s* and *s*, formed from soft drawn cop-

Fig. 360.—Wound Type of Rotor Complete with Slip Rings.

per, are securely fastened to the bars so as to give a strong mechanical joint and one of very low electrical resistance.

The wound type of rotor is shown in process of construction

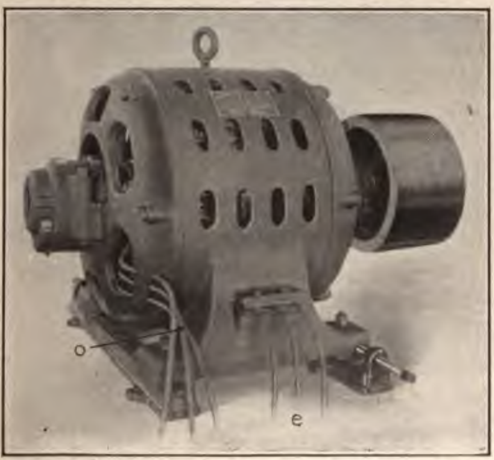

Fig. 361.—Wagner Wound-Rotor Type of Polyphase Induction Motor.

in Fig. 359, and in its completed form in Fig. 360, where the ends of the windings are connected to collector or slip rings *k*, *l* and *h*. Current is taken from the slip rings by low-resistance brushes, and leads as shown at *o* in Fig. 361 con-

nect the brushes with the starting resistance. In this Wagner polyphase induction motor the leads at *e* are from the stator winding.

1103. Do not the stators of different types of induction motors differ in construction?

No. If the supply current is the same, the stators of the different types of rotors are all of the same general construction.

1104. Show the starting resistance for a slip-ring type of induction motor.

Fig. 362 shows a dial form of starting resistance for a small

Fig. 362.—Dial Speed Regulator for Small Slip-Ring Type Induction Motor.

slip-ring type of induction motor. Connection with it is made at the three terminals near the bottom.

1105. Describe the construction of a rotor in which the starting resistance is mounted inside it.

The resistance consists of cast-iron grids enclosed in a triangular frame which is bolted to the end plates holding the rotor laminations together, and is short-circuited by metal brushes sliding along the inside surfaces of the grids. The

brushes are supported by a metal sleeve sliding on the shaft which is operated by a lever secured to the bearing bracket and located just above the bearing. In motors of medium sizes, a rod passing through the end of the shaft, as shown at *c* in Fig. 363, operates the short-circuiting arrangement in the triangular frame *m*.

For motors of over 50 horse-power, cylindrical coil resist-

Fig. 363.—Rotor with Self-Contained Starting Resistance.

ances of German silver wound on edge are used. These coils are bolted 120 degrees apart to bosses on the spider hub, and are clamped together by a ring on their front end. Two laminated metal brushes bear directly on each of these resistances and are supported on a yoke sliding on the shaft. The operation of this brush yoke is similar to that described for the cast-iron grid resistance, a lever being employed for this purpose.

1106. Illustrate and describe the method used in shifting the brushes on the slip rings to short-circuit the starting resistance.

Details of the brush shifting device are shown in Fig. 364. The component parts are the hand lever *A*, the toggle lever *C*, the connecting link *E F*, and the forked main shifting lever *D*. The hand lever is mounted on one end of a shaft *B*, at the other end of which is placed the toggle lever *C*. This latter is connected to the main shifting lever *D* by the connecting link *E F*, one part of which screws into the other. The jaws

of *D* which work in the groove of the brush sleeve *K* are provided with rollers *G* to minimize the wear of the lever jaws and the brush sleeve during the starting period.

The limit of travel inward is set by the lower end of the toggle lever *C* striking a pad on the arm of the bearing bracket. In the end of *C* is a pin *H* which is pressed outward by a spring *J*. During the operation of starting, this spring is compressed by the pin bearing on the pad. As soon as the pressure of the hand is removed from the hand lever,

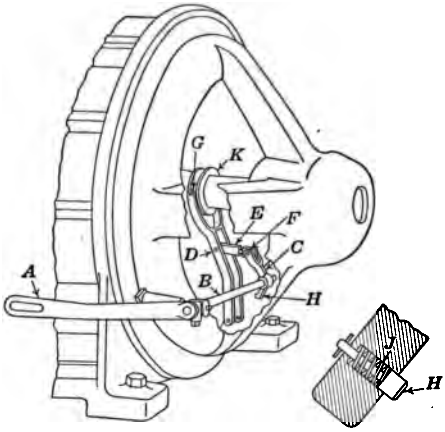

Fig. 364.—Brush Shifting Device used to Short-Circuit the Starting Resistance.

the spring expands, pushing the levers backward so that the rollers are central in the brush sleeve groove when the rotor is in its central position, that is, with the end play equally divided between the bearings. A 75 horse-power General Electric induction motor equipped with this device is shown in Fig. 365.

1107. What are the points of difference between the different types of induction motor?

The squirrel-cage type is the simplest in construction and the most substantial, because the rotor conductors are massive rods or bars, permanently connected to heavy rings at the

ends of the core and there is only one conductor in each slot. There are no sliding contacts, brushes or switches in the machine, and it therefore requires the least amount of care.

The wound type with the resistance mounted on the rotor is the next simplest, considering the complete motor and controller as a unit, but the motor itself is not so simple and rugged as the wound type with separate resistance, because

Fig. 365.—General Electric Polyphase Induction Motor equipped with Brush-Shifting Device in Fig. 364.

the slip rings and brushes are naturally less liable to derangement than the resistance and short-circuiting switch or lever mounted on the rotor.

1108. How do the three types compare in operation?

The squirrel-cage type requires a much larger starting current than the others and has less torque during the starting and accelerating period. The wound type with contained resistance and starting switch takes more starting current and

gives less starting torque than the wound type with external controller, because there is not room for sufficient resistance and switching equipment to put it on equal footing with the other motor, which is not limited in these respects.

1109. For what classes of service should the different types of induction motors be chosen?

The squirrel-cage motor is best adapted to service where it can run continuously, where expert attention is not available, or where the heavy starting current is not a disadvantage. It should not be put in where a motor must start up with the load on it.

The wound types are preferable under conditions where frequent starting and stopping are required, and they are indispensable where this condition exists and incandescent lamps are supplied from the same circuit or bus-bars. As between the two kinds of wound-type rotors there is not much choice; the contained resistance is usually put on motors of small and medium sizes and the external resistance is used with large ones. Where a heavy load must be started, as with an elevator, the external resistance has the advantage, because of the greater space available.

1110. Are commutators ever used on alternating-current motors?

Yes; commutators are used on some single-phase motors to make them start automatically under load when connections with the supply circuit are closed. An ordinary single-phase induction motor will not start of itself, like the polyphase motors previously shown, when current is passed through the stator winding.

1111. Why is the ordinary single-phase induction motor unable to start itself?

Because the magnetic field set up by the winding is stationary and merely induces currents in the rotor conductors exactly as the primary winding of a transformer induces current in the secondary winding. The currents in the rotor

conductors do not react on the field in such a way as to cause the rotor to turn, and it must, therefore, be started by some external means. The single-phase commutator motor starts automatically, and with a fairly good power factor.

1112. For what kind of work is this commutator type of single-phase alternating-current motor particularly adapted?

For driving machines up to about 5 horse-power either at constant, varying or adjustable speed. They are suitable for operating, at constant speed, machines demanding acceleration under full or overload torque such as air compressors, refrigerating machines, house pumps, etc. They are also designed for running machinery whose operation demands

Fig. 366.—General Electric Single-Phase Compensated Repulsion Motor.

certain speed variation against approximately constant torque, such as printing presses; and for adjustable speed requirements over a considerable range where the speed at a fixed controller setting must remain practically constant at any load within the motor's rated capacity, such as in machine tools and similar apparatus.

1113. Illustrate a single-phase commutator motor and describe the principles upon which it operates.

A General Electric motor of this type is shown in Fig. 366.

While the stator is very similar to that of an induction motor, the rotor resembles the armature of a direct-current motor. Referring to Fig. 367, which is a diagram of its connections and windings, the armature or rotor is provided with a wind-

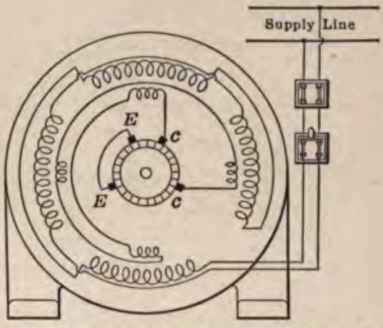

Fig. 367.—Circuits of a Compensated Repulsion Motor.

ing of the "two-circuit" drum type, connected to an ordinary commutator upon which press two sets of brushes E and C. The pair E, called the "energy" brushes, is permanently short-circuited and displaced at an angle to the lines of field

Fig. 368.—Unwound Field Frame of Motor in Fig. 366.

Fig. 369.—Coils in Place on Field Frame shown Opposite.

or primary magnetization. The second set C, called the "compensating" brushes, is connected to a relatively small field winding which serves to induce in the armature an electromotive force that tends both to raise the power factor and to

maintain approximately constant speed at all loads. By the use of a controller arranged to insert resistance or reactance in series with the energy and compensating circuits of the rotor, the speed can be adjusted over a range of 2 to 1, ap-

Fig. 370.—Unwound Armature of Motor in Fig 366.

proximately one-half of this range below and one-half above synchronous speed. For example, if the normal speed is 1100 revolutions per minute, a maximum of 1500 and a minimum

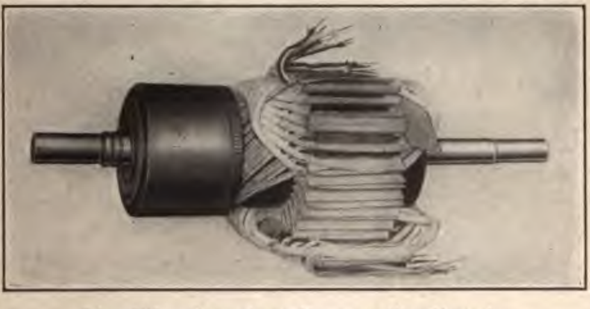

Fig. 371.—Armature Core partly Wound.

of 750 revolutions per minute can be obtained with the controller.

1114. Will the speed be constant when changed by the insertion of resistance?

The motor behaves like a compound-wound direct-current motor with resistance inserted in the armature circuit; loads within the motor's rated capacity have practically no changing effect upon the speed at a given controller setting.

1115. What kind of motor is the one just described?

It is a compensated repulsion motor. This name is given to it because the motion of the rotor is due to magnetic repulsion between the current in the short-circuited part of the winding and the stator field, and the undesirable reactions in the rotor winding are neutralized or compensated by the auxiliary field set up by the small stator winding connected to the compensating brushes.

1116. Illustrate and describe the construction of this compensated repulsion motor.

The unwound field frame, composed of laminations *r* assembled between cast-iron end flanges, *b* and *d*, is shown in Fig. 368. There are two field windings,—one comprising the main coils and the other the compensating coils. Both are shown in place in Fig. 369. The unwound armature is seen in Fig. 370, the steel laminated core for the coils being shown at *c* and the commutator composed of hard drawn copper segments at *t*. Fig. 371 gives an idea of the armature winding, which is similar to that on a direct-current armature. The completed machine was shown in Fig. 366.

1117. Are there any other forms of single-phase commutator motor?

Yes. There is a type of constant speed machine which acts as a repulsion motor while starting and is automatically changed to a simple induction motor when it reaches normal speed.

1118. Illustrate and describe the motor referred to in Answer 1117.

Fig. 372 is a view of a 20 horse-power Wagner motor of this type, and Fig. 373 shows the commutator end of the armature. A disk-shaped commutator is used and the brushes press horizontally against it, as may be seen from close inspection of Fig. 372. The brushes are connected together electrically by the metal collar to which the brush holders are bolted, and are therefore practically short-circuited, but they

are so spaced with regard to the stator field poles as to produce a strong repulsion effect in the armature or rotor. This causes the motor to start, and when it has nearly reached its normal speed, the brushes are lifted from the commutator

Fig. 372.—Wagner Single-Phase Commutator Motor.

and the commutator bars are all short-circuited; this changes the armature winding from the so-called repulsion type to what is practically the same (electrically) as a squirrel-cage

Fig. 373.—Armature or Rotor of Single-Phase Motor in Fig. 372, from Commutator End.

rotor. Then the machine runs as an ordinary induction motor.

1119. How are the brushes lifted and the commutator short-circuited?

By a centrifugal governor which works against a spring. The governor weights are located within the rear end of the

rotor spider, as shown in Fig. 374. By means of levers and links the governor weights slide the brushes away from the commutator and at the same time press a short-circuiting ring against the back face of the commutator, connecting all the bars together.

1120. How does the governor mechanism move the brushes away from the commutator?

A barrel slides along the shaft under the influence of the

Fig. 374.—Pulley End of Rotor in Fig. 373.

governor weights and the opposing spring; the governor weights move this barrel toward the commutator end of the

Fig. 375.—Brush Rigging of Single-Phase Commutator Motor in Fig. 377.

shaft and the spring moves it in the opposite direction. The collar to which the brush holders are bolted is cup-shaped, as shown in Fig. 375, and inside this collar a brass ring

" floats " between the ends of the brush-holder fingers (which project into the cup through slots) and the end of the sliding barrel on the shaft. When the speed is high enough for the centrifugal force in the governor weights to overcome the opposing spring, the barrel is pushed against the ring in the brush-holder collar; and the ring, pressing on the ends of the brush-holder fingers, pushes the brushes away from the commutator. The brush mechanism here shown is the one used on the Century motor illustrated in Fig. 377.

1121. **How is the stator winding of the motor in Fig. 377 arranged?**

Exactly like that of an ordinary single-phase induction motor. Fig. 376 is a picture of the stator and rotor, from

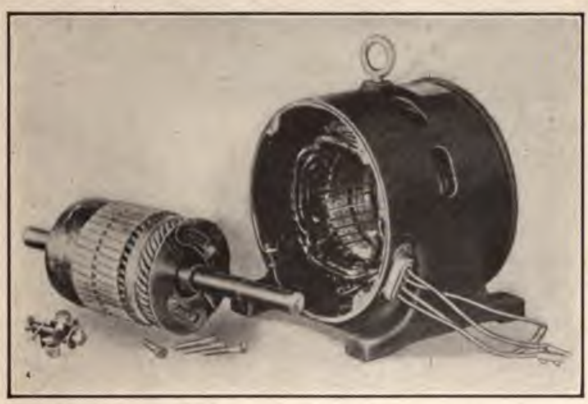

Fig. 376.—Stator and Rotor of a Single-Phase Motor similar to that in Fig. 377.

which it is evident that the stator core consists of slotted rings mounted in a circular frame or housing, and the winding is of the distributed type used in all induction motors of appreciable size. The machine here illustrated has four groups of coils which produce four magnetic poles on the inner face of the core.

1122. Is it necessary to use a commutator to make a single-phase motor start automatically?

No. A single-phase motor can be made to start without using a commutator if it is specially designed to operate in conjunction with certain conditions.

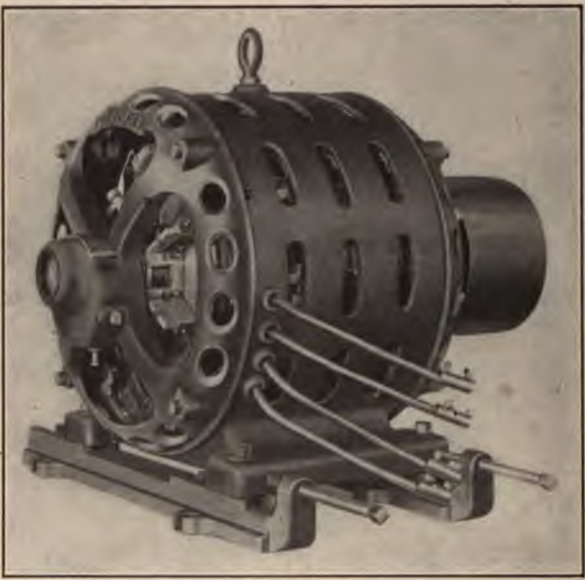

Fig. 377.—Single-Phase Commutator Motor built by the Century Electric Company.

1123. What method is used in place of a commutator to make a single-phase motor start itself?

An auxiliary stator winding is provided which produces a magnetic field that is out of phase with the field produced by the main winding. The result is a sort of rotating field somewhat like that produced in a polyphase motor, but not so uniform or regular in its variations. This rotating field serves well enough to start the rotor, however, if there is no load on it while starting, and after it has reached about 75 per

cent. of its normal speed the load is picked up by the automatic action of a centrifugal clutch. Fig. 378 shows a motor of this kind.

1124. Describe the construction of the motor in Fig. 378.

The rotor is of the ordinary smooth core squirrel-cage type. The stator is of the same general construction as that of the ordinary three-phase induction motor, consisting of a formed coil winding with three taps taken off it, as shown at *A* in Fig. 379. These are wired, as indicated diagrammatically in Fig. 379, through a starting box *B* and main switch *C* to the supply wires of the circuit *m n*.

Fig. 378.—Single-Phase Self-Starting Induction Motor without Commutator. Made by the General Electric Company.

In starting, the switch *C* is closed and the arm *r* of the starting box is placed on the contact *o*, which is connected through a resistance *d* with one of the taps of the stator winding and through a reactance *h* with another of the taps of the stator winding. The current entering at *n* is therefore

changed into currents of different phase with respect to each other before entering the stator winding and in passing through them combine to form a resultant rotating magnetic field which pulls the rotor around with it. After the rotor has attained a good starting speed the arm *r* is switched over to

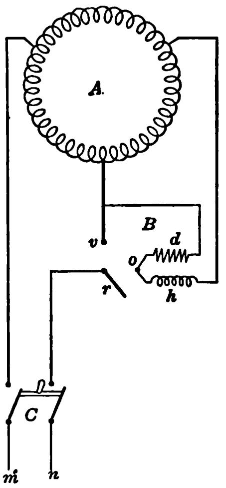

Fig. 379.—Connections for Single-Phase Motor in Fig. 378, showing Method of Starting.

the contact *v* and the machine operates as a single-phase induction motor.

The automatic clutch which picks up the load when the speed reaches a certain amount is shown in Fig. 380 mounted on the near end of the rotor. It consists of a band *t l*, mounted on the rotor *p*, so that when *p* is in place on the shaft *f*, the band fits inside the pulley *y*. The centrifugal force is sufficient at 75 per cent. normal speed of the motor to spread open the band against the action of the spring *s* so that the band rigidly engages with the inside of the pulley and causes it to rotate and pick up the load.

1125. What are the advantages and disadvantages of single-phase motors over two-phase or three-phase motors?

A single-phase motor requires only a single transformer and two lead wires; this makes for a lower installation cost and smaller transformer losses than with polyphase motors, which require additional transformers and lead wires, and especially on a long transmission system the saving in copper wire is an important advantage. A single-phase motor can be supplied from any alternating current—single-phase, two-phase or three-phase. The self-starting type has the addi-

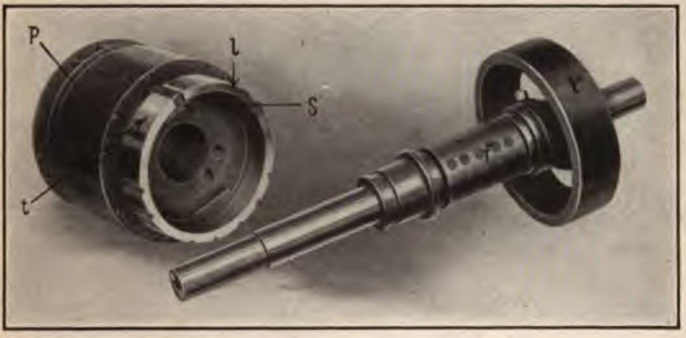

Fig. 380.—Rotor of Single-Phase Motor in Fig. 378, equipped with Automatic Clutch; also the Shaft and Pulley.

tional advantage that it can be thrown on and off the circuit from a distance by means of a simple knife switch.

On the other hand, its first cost is higher owing to a more complicated arrangement for starting, and for the same reason it is more liable to trouble, usually weighs more and has greater friction of moving parts; its efficiency is also lower.

1126. How are single-phase motors connected to two-phase circuits?

If the circuit is of the proper voltage for the motor, it is connected directly to either of the two "legs" or phases of the circuit, but if the circuit is a high-voltage primary line, a transformer must be used between the line and the motor; in that case the transformer may be connected to either leg

of the supply circuit. Fig. 381 is a diagram showing these methods. The motor *A* is connected directly to a 110-volt lighting circuit which is supplied through a transformer from one leg of a two-phase primary circuit. The motor *B* is supplied through a transformer from the other leg of the same

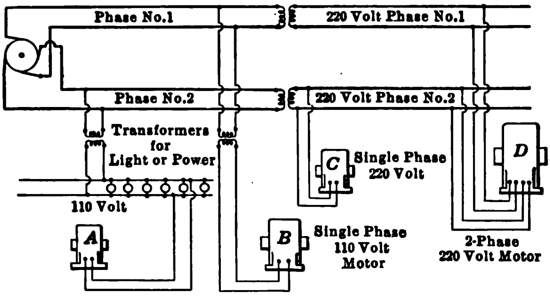

Fig. 381.—Connections for Single-Phase Motors on a Two-Phase Circuit.

primary line, and the motor *C* is connected to one leg of a secondary 220-volt circuit which delivers current also to a two-phase motor *D*.

1127. How are single-phase motors connected to a three-phase circuit?

Each motor is connected to two wires of the circuit, either

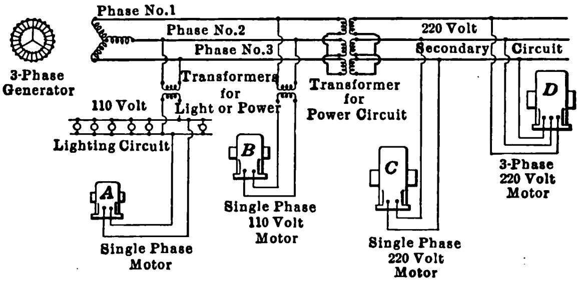

Fig. 382.—Connections for Single-Phase Motors on a Three-Phase Circuit.

directly or through a single transformer. Fig. 382 shows connections in which each motor is connected in the same way, relatively, as the motor bearing the same letter in Fig. 381.

1128. **Are there any disadvantages in the operation of single-phase motors on two-phase and three-phase circuits?**

Yes. Both two-phase and three-phase circuits should be balanced as to the division of load between the different phases, and a single-phase motor operated on one phase or leg will unbalance the system. It is important, therefore, to have the same total motor load connected to both legs of a two-phase system or to all three legs of a three-phase system, and it is almost impossible to get such a division of load with a large number of single-phase motors on either of the systems, especially a three-phase system.

MOTOR-GENERATORS, DYNAMOTORS AND ROTARY CONVERTERS

1129. What distinction is there between these three types of machines?

A motor-generator consists of a motor, either direct-current or alternating, direct connected to a direct-current or alternating-current generator, both motor and generator being usually mounted or arranged to be mounted upon a single base, as in Figs. 383-386. Of these possible combinations that of an alternating-current motor direct connected to an alternating-current generator is practically never used, because a transformer would answer the purpose in a much cheaper and simpler manner.

In a dynamotor, two armature windings are put on one core and a single field-magnet frame suffices, as in Fig. 387. One of these windings is a motor winding and the other a generator winding, and either or both of them may be for either alternating current or direct current. Two alternating-current windings are never used, however, for the same reason as above, namely, a transformer is simpler and cheaper.

A rotary converter has only one armature winding, which is connected to a commutator exactly like a simple direct-current machine, but is also connected to collector rings like a closed-circuit alternating-current armature winding would be. A converter can either receive direct current and deliver alternating, or the reverse. It is not intended to deliver the same kind of current that it receives.

1130. Under what conditions are the different machines used?

When there is considerable difference between the voltage

it is intended to deliver to the machine and that which it is desired to obtain from it, or when the delivered voltage must be varied considerably, the motor-generator type is preferable because of the better opportunity for insulating the high-potential circuit from the low-potential one, and because the generator voltage can be adjusted independently of the motor voltage.

Motor-generators are extensively used as boosters in electric lighting. On long lines the drop of potential may be such as to make the voltage for lamps at a distance from the station too low for securing the same illumination as in lamps near the station. In such cases a motor-generator is connected at its motor end to the station bus-bars from which the main lines lead, and the field and armature windings of the generator are connected in the feeder circuit in series so that the field strength increases as the load on the feeder increases and the armature adds greater pressure in proportion. This boosting effect is made such that the added voltage is enough to compensate for the drop in the line wires. Motor-generators also provide direct current for storage battery charging, using the power furnished by alternating-current circuits in connection with garages, railway signal systems, etc.; they also furnish direct current for arc lights in moving picture outfits or similar work where the flicker or noise of alternating-current arcs is objectionable.

Dynamotors and rotary converters are more efficient, simpler in operation, more compact and cost less than motor-generators so that they are preferable when the voltage difference is not great and the generator voltage does not need to be varied—widely. For charging storage batteries, furnishing ringing current in telephone exchanges, supplying current for testing or experimental work of various kinds in which no great flexibility of voltage regulation is required, and for other purposes requiring small current output, the dynamotor is used. The use of the rotary converter is chiefly in substations where it converts the alternating cur-

rent sent from the central generating station into direct current for distribution.

1131. Under the conditions just described, is there not a great difference between the alternating- and direct-current voltages handled by the converter?

There would be considerable difference if the voltage of the incoming alternating current was not reduced by means of step-down transformers before being applied to the rotary converter. There is a fixed ratio that exists at all times between the alternating-current voltage and the direct-current voltage of a rotary converter, and the latter is always the higher, the proportion being given in Answer 1140.

1132. Describe briefly the differences between the motor-generators shown in Figs. 383 to 386.

The motor-generator in Fig. 383 comprises a three-phase motor *a* and a direct-current generator *c*. The rotor of *a*

Fig. 383.—Small Motor-Generator Set, comprising an Alternating-Current Motor and Direct-Current Generator.

and the armature of *c* are mounted on a common shaft, and as the two frames are fastened together to form a rigid self-contained structure, no sub-base is required and the set may be bolted directly to the floor or foundation.

The motor-generator set in Fig. 384 comprises a direct-current motor *d* and a direct-current generator *h*. The frames

are riveted together. Both machines are of small size, the generator being 13 kilowatts. Like the preceding set it is of General Electric make.

Fig. 384.—Motor-Generator Set, comprising a Direct-Current Motor and Direct-Current Generator.

The outfit in Fig. 385 is a Westinghouse 50-kilowatt motor-generator set comprising a polyphase induction motor *m* driv-

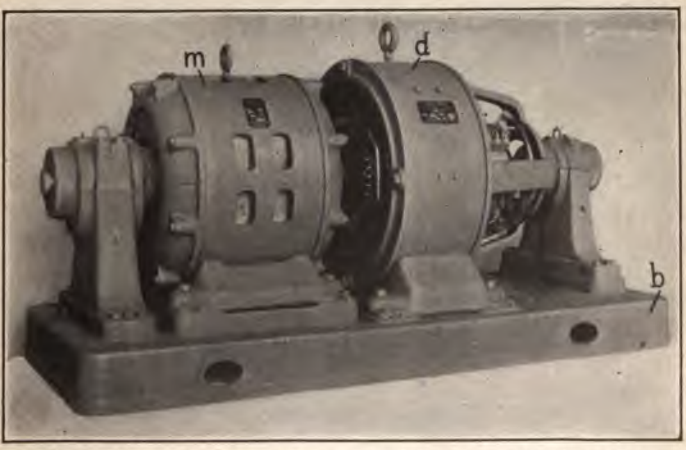

Fig. 385.—Motor-Generator Set, comprising an Induction Motor and 50-Kilowatt Direct-Current Generator.

ing a direct-current generator *d*. The machines are mounted on a substantial sub-base *b* which forms a part of the set.

The distinguishing features of the Crocker-Wheeler set in Fig. 386 are the motor *M*, which is of the alternating-current synchronous type, and the generator *G*, which is a direct-current machine with commutating poles and delivers 1200 kilowatts.

1133. Describe the machine shown in Fig. 387.

This machine is a dynamotor with a direct-current motor winding and an alternating-current generator winding. It

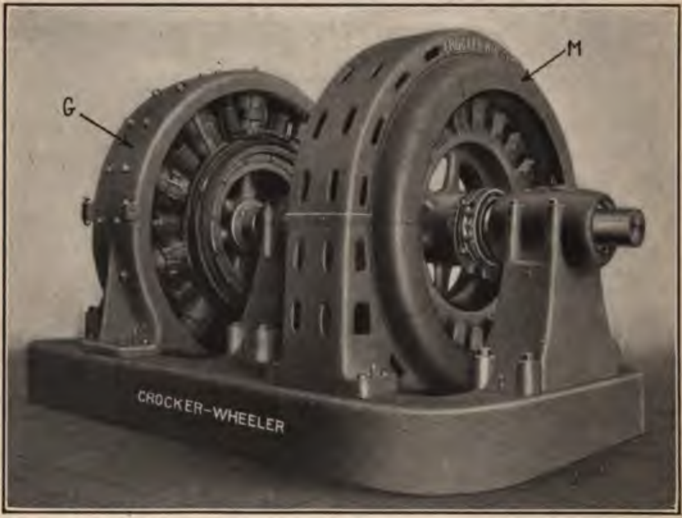

Fig. 386.—Motor-Generator Set, comprising a Synchronous Motor and 1200-Kilowatt Direct-Current Generator.

is built to run as a motor on a direct-current circuit and deliver alternating current for ringing purposes. The field-magnet coils *m* and *n* of the two-pole magnet *a b* are excited by direct current from the supply circuit. The direct current or motor end of the machine is at the left, as indicated by the commutator at *c*, and the alternating current or generator end of the machine is at the right, as indicated by the collector rings at *u* and *r*. The two windings on the armature *s* are electrically separate, although they are upon the same core.

1134. Describe the dynamotor shown in Fig. 388.

This machine is provided with a direct-current motor winding and a direct-current generator winding, the difference

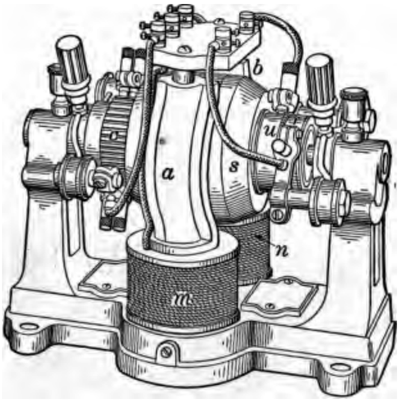

Fig. 387.—Dynamotor containing Direct-Current Motor Winding and Alternating-Current Generator Winding.

being only in voltages. It was built for charging small storage batteries, the voltage required for this purpose being usually much less than that of the supply circuit from which the

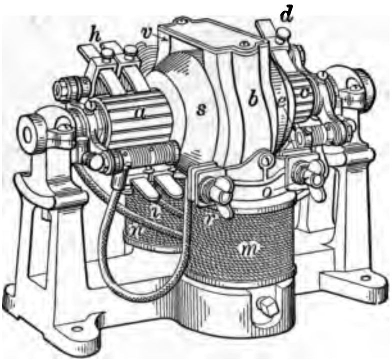

Fig. 388.—Dynamotor containing Direct-Current Motor and Direct-Current Generator Windings.

dynamotor is operated. The coils *m* and *n* of the field magnet *v b* are excited with direct current from the electric light

or power wires to which the machine is connected. The commutator *c* is on the motor end and the commutator *a* on the generator end, the brushes *d* and *e* taking current from the service wires, and the brushes *h* and *i* delivering current for charging the battery.

1135. Are all rotary converters of the same type?

No; there are two kinds of rotary converters: the direct-current field type and the induction field type. As the latter must be more carefully designed for the circuits on which they are to be run and are considerably more sensitive to

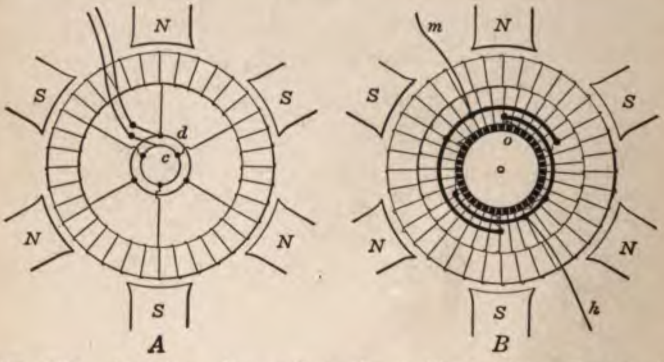

Fig. 389.—Armature Connections in a Single-Phase Rotary Converter.

disturbances than the former type, the majority of rotary converters in commercial use are the direct-current field type. The field magnets of this type are similar to those of a direct-current dynamo; hence the name.

1136. Show the armature connections of a rotary converter of the direct-current field type.

Fig. 389 shows the armature connections of a single-phase, six-pole rotary converter of this type. The part *A* shows the alternating-current or motor side of the machine, and the part *B* shows the direct-current or generator side. These are opposite ends of the same armature and of the same set of magnet poles. Both the armature and the magnet poles are

wound as they would be for any direct-current, six-pole machine.

The connections on the alternating-current side A will perhaps be best understood by referring first to a simple direct-current, two-pole generator. To convert this into a single-phase alternating-current motor, it is necessary merely to connect two diametrically opposite points of the armature winding to two separate collector rings. In Fig. 389 there are six field-magnet poles instead of two as in the case just considered, so that instead of joining two equidistant points in the armature winding to the collector rings, 3×2 or 6 equidistant points around the armature are thus alternately connected to the two collector rings c and d.

1137. Explain the operation of the converter armature just described.

With a single-phase alternating electromotive force applied to the collector rings c and d by means of the brushes pressing on them, and with the field magnet excited, the armature, when once started, will continue to rotate and will run as an alternating-current motor. Part of the alternating current fed into the armature for running it is led to the commutator o on the direct-current side B, and is converted into direct current in the usual way. This direct current passes through the brushes pressing on the commutator and thence to the outside circuit $m\,h$. By reason of the rotation of the armature windings in the magnetic field, alternating electromotive forces are developed in them; these electromotive forces, however, oppose those applied at the alternating-current end. The current in the armature windings is due to the difference between the alternating electromotive forces and the direct-current electromotive forces; it is therefore comparatively small and produces but little heat in these conductors.

1138. Are single-phase rotary converters generally used?

They are seldom used on account of their inability to start themselves as alternating-current motors. Two-phase and three-phase and six-phase rotary converters are more satis-

factory in this respect. They operate on the same principles as the single-phase converter, but two-phase converters have four collector rings connected so as to give two circuits through the armature winding under each pair of poles. The rings are connected to four equidistant points in each section of the armature winding covering the space spanned by one pair of poles. Three-phase converters have three collector rings connected so as to give three circuits through the armature winding under each pair of poles. The rings are connected to three equidistant points in each section of the armature winding covering the space occupied by one pair of poles. Six-phase converters are seldom used except in sizes above 500 kilowatts on account of the greater complication of transformers and collector connections.

1139. What other advantages have polyphase converters in addition to being able to start themselves?

The average path of the current through the armature from the collector rings to the brushes is short, so that the armature resistance loss and the armature reaction are small, and the efficiency is high. On account of low armature loss in comparison with that in direct-current generators of equal output, the load on a two-phase converter can be increased about 60 per cent., and the load on a three-phase converter can be increased about 30 per cent., above their respective outputs as direct-current machines.

1140. What relation exists between the alternating voltage applied to the motor side of a rotary converter and the direct-current voltage available at the generator side?

In either a single-phase or a two-phase converter the applied alternating voltage is approximately 0.71 of the voltage on the direct-current side. In a three-phase converter the applied alternating voltage is approximately 0.61 of the direct-current voltage. In a six-phase converter it is 0.71 or 0.61, depending upon whether a diametrical or double mesh connection is used for the transformers.

1141. To obtain direct current at 550 volts from a two-phase rotary converter, what alternating voltage must be applied?

According to Answer 1140, there must be $0.71 \times 550 = 390.5$ volts.

1142. What direct-current pressure would be developed in a three-phase converter supplied from a 500-volt alternating-current circuit?

According to Answer 1140, there would be developed $500 \div 0.61 = 819.7$ volts.

1143. What effect has the frequency of the alternating-current circuit upon the design and operation of rotary converters?

High frequency supply entails high peripheral speeds and narrow commutator bars, and these introduce serious difficulties in the mechanical construction. Frequencies of 40 cycles, or better still 25 cycles, per second, give the most desirable results.

1144. Illustrate and describe the construction of a rotary converter.

A Westinghouse six-phase rotary converter of 3000 kilowatts output, is shown in Fig. 390. The six-phase alternating current is obtained by special connections of transformers supplied from a three-phase circuit, the advantage over a three-phase machine being a lower armature copper loss. The machine in Fig. 390 is self-starting and delivers direct current at 600 volts.

In structural features it conforms so closely to the construction of direct-current generators that a detailed description is unnecessary. In electrical details it is also very similar to those in direct- and alternating-current generators. The direct-current side of the machine is at the left and the alternating-current side at the right, although there is but one armature and field. The armature coils are cross-connected at points of equal potential, and taps leading to the collector rings at *c* are brought out from the armature winding, as

explained in connection with Fig. 389. Equalizer rings equalize the current flowing in the several armature circuits so that a uniform density is secured beneath each pole piece to insure good commutation. The field magnets are compound wound, the heavy connections between the series coils being

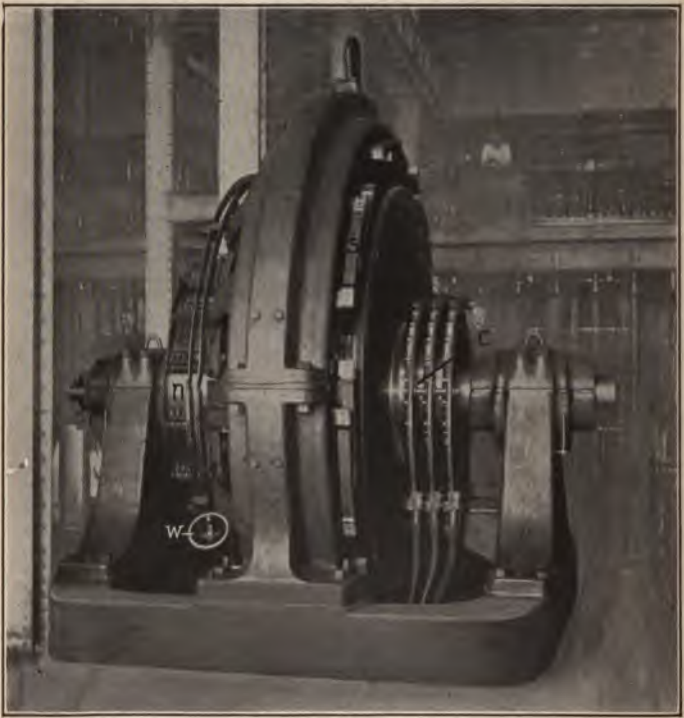

Fig. 390.—Westinghouse Rotary Converter.

shown at *s*, etc. The movement of the brushes on the commutator *n* is accomplished by means of the hand-wheel *w* which gears into the rocker arm.

1145. What means is available for the regulation of the direct-current voltage under varying load?

Automatic regulation of the direct-current voltage under

varying load is possible within narrow limits by a properly proportioned series field winding and inductance, the latter either in the transformer, or in choke coils installed between the transformer and the rotary converter. Non-automatic regulation can be obtained by the use of voltage regulating dial switches connected to taps in the transformer windings, or through potential regulators, induction regulators, synchronous regulators or alternating-current boosters. Rotary

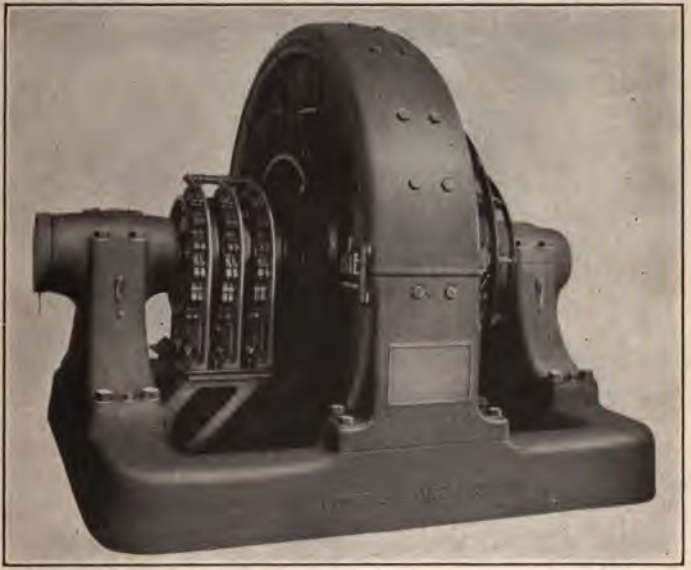

Fig. 391.—Regulating Pole Rotary Converter built by the General Electric Company.

converters are also built with regulating poles to answer the purpose.

1146. Show a regulating pole rotary converter and explain its principle of operation.

Fig. 391 shows a General Electric machine of this type with ten poles. It has an output of 1000 kilowatts, a speed of 300 revolutions per minute and a range of voltage from 240 to 300.

To explain its principle of operation, reference will be made to Figs. 392 and 393. Consider, first, the former of the two diagrams, where the regulating poles *R* are shown with a width equal to 20 per cent. of the width of the main poles *M*. Suppose that the machine at normal speed, with the main poles excited to normal density, but with no excitation on the regu-

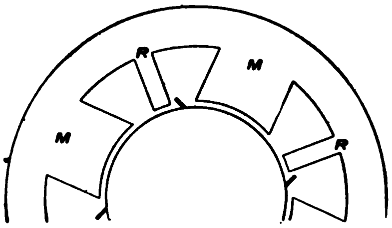

Fig. 392.—Diagram illustrating Principle of Regulating Poles in a Rotary Converter.

lating poles, gives 250 volts direct current. Then with each regulating pole excited to the same density as the main poles, and with a polarity corresponding to that of the main pole in the same section between brushes, the direct-current volt-

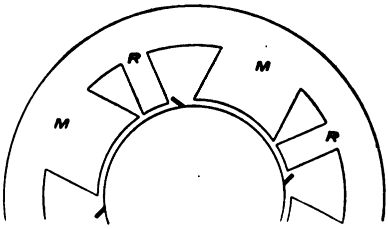

Fig. 393.—Diagram showing Actual Position of Poles on Machine in Fig. 391.

age will rise to 300 volts at the same speed, since the total flux cutting the conductors in one direction between brushes has been increased 20 per cent. If, on the other hand, the excitation of the regulating poles is reversed and increased to the same density as that of the main poles, the direct-current voltage will fall to 200 volts, since in this case the

regulating poles give an electromotive force opposing that generated by the main poles. If the main field excitation is kept constant, the change in the excitation of the regulating poles to cause these results does not alter the alternating-current voltage. In practice it is not necessary to have so wide a range of voltage and it is found preferable to place the regulating pole closer to the corresponding main pole, as in Fig. 393; this construction is therefore followed in the machine shown in Fig. 391, where the voltage range is 60 and the rotation of the armature is from the brushes toward the main poles, as indicated by the slant of the brushes in the diagram.

1147. How are rotary converters usually started?

By applying alternating current directly to the collector rings, so that the converter starts as an alternating-current induction motor; or by means of a separate alternating-current motor connected to the converter shaft; or by applying direct current to the commutator so that the converter starts as a direct-current shunt motor.

1148. Describe in detail the starting of a rotary converter by applying alternating current to the collector rings.

This method is applicable with polyphase converters, but not with single-phase converters. The field winding is open-circuited at several points by means of a suitable switch in order to reduce the strain on its insulation by limiting the voltage induced in the field winding by the alternating current in the armature. Self-starting rotaries are also generally equipped with a switch for disconnecting the series shunt from the series field, during starting, so as to prevent the circulation of an induced current which would otherwise produce a braking effect. The direct-current side of the machine is disconnected from its circuit during the starting process, as the current produced is alternating until synchronism is reached. The moment of synchronism can be

judged by means of incandescent lamps connected across the leads from the brushes. When synchronism is reached, the lamps give a steady light. The field circuits may then be closed, the direct-current side connected to its circuit and the load thrown on.

1149. Describe the starting of a rotary converter by means of a separate alternating-current motor connected to the converter shaft.

The motor used for this purpose is of the "induction" type and is designed with a smaller number of poles than the converter, so that its normal speed will be higher than that of the converter and it will therefore be able to bring the converter up to synchronous speed. The converter armature is entirely disconnected from both the alternating-current and direct-current circuits, its field is excited and the induction motor is started up in the ordinary way. When the converter has been brought up to synchronism with the alternating-current circuit the switches in the leads to that circuit are closed. The induction motor is thereupon cut out of circuit, leaving the converter running as a synchronous motor. Then the direct-current switches are closed. This method is desirable where the starting current must be kept as low as possible because of limited capacity of generator or transmission system.

1150. Describe the starting of a rotary converter by applying direct current to the commutator.

The converter is started as a shunt-wound motor. If the field magnet is compound wound, the series field must be opened, else the current flowing in it will buck the shunt field and may even prevent the machine from starting. A strong field is given the converter in starting, and the current through the armature is gradually increased by means of a starting rheostat in series with the direct-current side of the converter. The speed of the converter is increased by means of the rheostat in the shunt-field circuit until the converter is in syn-

chronism with the alternating-current supply circuit, and when synchronism is established the main alternating-current switches are closed and the main direct-current switches opened. On account of the low resistance of the converter armature it is often a difficult matter to determine the exact instant when the proper phase relations are established, but if this has been correctly judged and the switches quickly thrown, the converter will immediately fall in step with the alternating-current circuit and run as a sychronous motor.

1151. When starting with an auxiliary induction motor, or in the manner last described, what means are employed

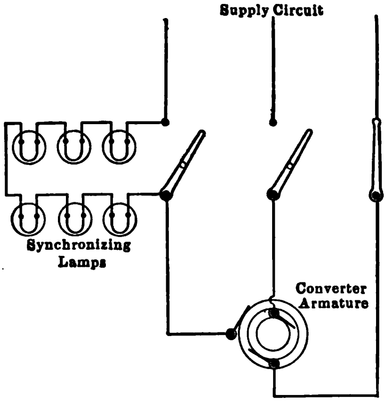

Fig. 394.—Synchronizing Connections of a Converter when starting as a Direct-Current Motor or by means of an Auxiliary Motor.

to determine when synchronism between the converter and the alternating-current supply is established?

Incandescent lamps connected as in Fig. 394 will show when the proper phase relations are established. With the lamps connected across one of the main alternating-current switches and either of the other two switches closed, the full lamp current will flow from the alternating-current circuit through the lamps and one branch of the armature winding, so long as the converter is motionless. When it is revolving, its electromotive force opposes the circuit electromotive force

whenever the two are exactly in phase and agrees with it when they are opposed in phase. Consequently the lamps are lighted and extinguished alternately, as the converter speeds up, the flickering becoming slower as the converter approaches synchronous speed. At synchronism, the lamps remain dark; then the two open switches should be closed without delay.

1152. Would a slight variation in the frequency of the supply circuit cause any noticeable effect in the operation of a rotary converter?

It would tend to cause a varying speed of the armature with respect to the impressed voltage. This objectionable feature is called hunting.

1153. Can the hunting of rotary converters be prevented in any way?

The tendency to hunt can be greatly reduced by increasing the inductance of the armature; this is done by placing the armature windings in deep slots having teeth with projecting heads. Hunting can also be checked by providing the pole-faces with heavy copper grids that extend across them and are inbedded in slots. The grids serve as dampers to the hunting effect, their action being analogous to that of a dash-pot on an engine governor.

1154. Is it not customary to employ some device on rotary converters to produce end play?

Yes, a device called an oscillator is generally used for this purpose because the armature shaft of a rotary converter will not of itself take on a back and forth movement in the bearings, as in other machines, and consequently the brushes are liable to wear channels in the commutator or collector rings unless some such device is used.

1155. Show an oscillator and describe its principle of operation.

Fig. 395 shows one of these devices at *a* mounted on the end of the armature shaft. It consists of a steel plate with

grooved ball race and ball, backed by a spring. As the grooved plate is mounted not quite parallel to the end of the shaft, the hardened steel ball is caught at the lowest point between the race and the end of the shaft. As the armature revolves, the ball is carried upward and the spring compressed. The reaction of the spring forces the shaft away and the ball falls back to its normal position. Thus a periodic longitudinal motion is imparted to the armature as it revolves

Fig. 395.—Oscillator and Speed-Limiting Device.

and uniform wear of commutator and collector rings is assured.

1156. What is the purpose of the switch C, Fig. 395?

It forms part of a safety device to prevent trouble in case the rotary converter exceeds its speed limit. Under normal conditions the switch is held open, as represented in Fig. 395, by a pivoted latch, but when the speed becomes too high the action of a centrifugal governor attached to the shaft trips the latch and releases a spring which closes the switch. The closing of the switch completes an auxiliary circuit through the tripping coils of the circuit breaker in the direct-current

mains and thus opens the main circuit if the speed becomes too high.

1157. Can rotary converters be operated in parallel?

Yes. If they are to be operated in parallel on the direct-current side, they are connected in parallel like shunt or compound direct-current generators. With compound-wound rotaries an equalizing connection, similar to that employed between series fields in direct-current generators, must be made between the machines. The load should be divided among the machines as nearly equal as possible either by regulating the alternating voltage, or by varying the field current, or, to a slight extent, by changing the position of the brushes on the commutator. When rotary converters are to be operated in parallel on the direct-current side and take their supply current from a single alternating-current system, separate transformers must be provided for each converter. A single set of transformers may, however, be used if there be separate secondaries for the converters.

1158. What should be done in case a rotary converter flashes over or the direct-current circuit breaker operates on account of excessive current?

The deflection of the direct-current voltmeter needle should be noted to see that the field has not been reversed in polarity. If the polarity has not changed, the deflection will be in the usual direction. If the polarity of the field has changed, there will be no deflection, or there will be a slight one backward, and the polarity must be reversed by remagnetizing the field magnets from the direct-current circuit. After a converter flashes over, it should, if possible, be shut down for a moment and the commutator cleaned of any burs that may have resulted.

1159. In case the alternating-current circuit breakers operate, what should be done?

The direct-current circuit breaker and switches should be opened, and the converter synchronized as in first starting.

1160. If the power in the alternating-current circuit ceases, what should be done?

Shut down the rotary converter immediately, opening all the switches. The synchronizing device should then be connected up so the lamps will light and thus show when the power is again ready for starting the converter.

1161. How should a rotary converter be shut down?

First, the direct-current circuit breakers should be opened, thus removing the load from the machine. Then, in turn, the direct-current switches, the alternating-current circuit breakers and the alternating-current switches should be opened. All the resistance should be introduced in the rheostat and the synchronizing device cut out of circuit. Before the converter stops, the commutator should be wiped off. Then the brushes should be examined and the whole machine cleaned thoroughly.

1162. Can a rotary converter be used for changing direct current into alternating current?

Yes. It is then called an "inverted" converter. The machine is separately excited and one rheostat is required in the converter field circuit and another in the field circuit of the exciter. The rheostat in the converter field circuit is used only in starting and should be cut out when the converter is in normal operation.

1163. Does the operation of an inverted rotary converter differ from that of a rotary converter as already described?

Yes; an inverted rotary converter does not operate at constant speed as in the previous case. Its speed depends upon the strength of its field magnet and consequently upon the reaction of the armature current upon the field so that it varies according to the alternating-current load. If this load be a heavy inductive one, the speed may become very high. This may, however, be prevented by exciting the converter from a generator driven by the converter, so that its speed varies with that of the converter. A change in the speed of

the converter will then cause a similar change in the excitation voltage and this, in turn, will produce a corresponding variation in the converter field-magnet strength. Care must be taken always to start an inverted rotary converter with load, as otherwise it is liable to run away.

1164. If a rotary converter be driven by outside mechanical power, could it be used as a generator?

Yes. It is then called a double-current generator, because it can supply both alternating and direct currents. The capacity of a machine thus operated is no greater than that of a direct-current generator of the same total output. This is true because the heating of the armature depends on the sum of the currents in it, and not on their difference, as when the machine is operated as a rotary converter. Separate field excitation alone is advisable for a double-current generator.

1165. Are double-current generators adapted for any particular class of work?

Yes; they are adapted for service where direct current can be employed in a certain district for a part of the day and alternating current used in some other district for another part of the day. The machine is then kept under practically constant load and takes the place of two different types of generators.

INCANDESCENT LAMPS

FILAMENT LAMPS

1166. How is light produced in an incandescent lamp?

By passing a current of electricity through a conductor so as to heat it white hot. The conductor that is heated is called the " filament," because it is in the form of a thread. The filament is made very small in cross-section in order to make its resistance high and thereby reduce the current required to heat it.

1167. Does not the filament burn away rapidly because of being kept white hot?

It would if exposed to the air, because substances heated

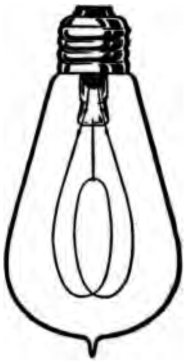

Fig. 396.—Carbon Filament Lamp.

to a burning temperature in air are readily destroyed by oxidation. In order to prevent this, the filament is mounted within a sealed glass bulb from which the air has been pumped out.

1168. What is the usual construction of the lamp?

Most incandescent lamps follow the construction shown in Fig. 396. The lamp comprises three parts: a glass bulb, the filament and a metal base.

1169. Of what is the filament made?

The ordinary carbon filament is made of cellulose—a sticky substance made by dissolving absorbent cotton—which is forced through a small hole to give it the form of a thread. After being hardened, it is cut to the proper length, wound on a form to give it the proper shape and carbonized.

1170. What determines the thickness of the filament?

The size of the hole through which the cellulose is forced. This is proportioned according to the required candle-power, voltage and current of the lamp filament.

1171. In what shapes are filaments made?

In almost every conceivable shape. Some of the more common ones are shown in Fig. 397, such as a plain loop *a*, a

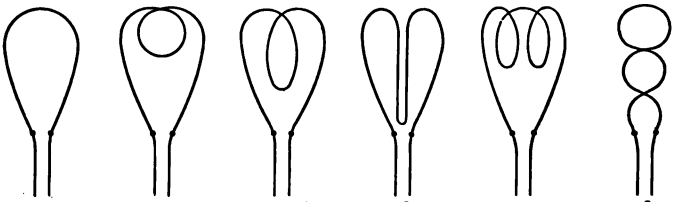

Fig. 397.—Different Shapes of Filaments used in Incandescent Lamps.

circular loop *b*, an oval loop *c*, a double filament *d*, a triple filament *e*, or the shape may be that of a spiral as shown at *f*.

1172. How is the filament supported inside the lamp?

Two thin platinum wires *c* and *e*, Fig. 398, are fused through a small stem of glass which is solid at *n* but hollow at *m*, and the ends of the filament are fastened to *c* and *e* by carbon paste. Sufficient of this paste is used to prevent the heat of the filament, when the lamp is lighted, from harmfully heating the platinum wires. To afford additional security, the filament is anchored at *a* to a small platinum wire fused into the glass *n*. Small copper wires *r* and *s* are fused to the ends of the platinum leading-in wires *c* and *e*, for connection to the base. The glass stem *n m* is fused into the neck

end *i*, Fig. 399, of the lamp bulb and the air is pumped out through a small tubular extension *c* at the opposite end,

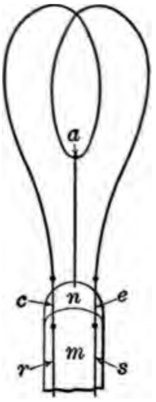

Fig. 398.—Method of Supporting the Filament.

after which the glass around the opening at *c* is fused together, leaving a small tip projecting outward, as shown at *d*.

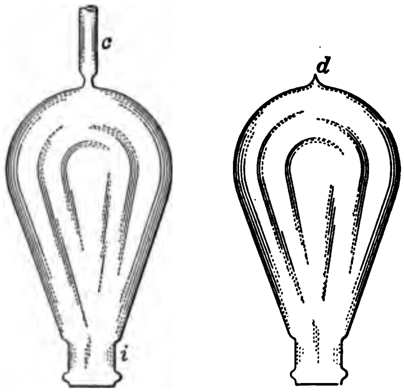

Fig. 399.—Progressive Stages in the Construction of the Bulb.

1173. **Why is platinum used for the leading-in wires?**

Because it does not corrode, and because the extent to which it expands under the influence of heat is practically the

same as that of glass. There is therefore no danger of the glass becoming cracked or of its expanding away from the wires and allowing air to leak into the bulb.

1174. How is the base made?

This consists of a coarse-threaded brass shell *h*, Fig. 400, in the center of which is a metal contact *o* fastened to, but insulated from, the brass shell by a circular piece *v* composed of porcelain or of a hard rubber or fiber composition. One of the copper wires leading to the filament is soldered to the

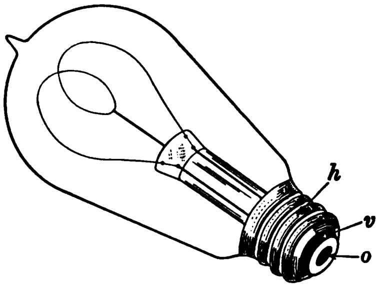

Fig. 400.—Nearby View of Base End of Lamp.

brass shell of the base and the other wire is soldered to the center contact *o* so that the two metal parts of the base form the terminals of the lamp.

1175. How is the base fastened to the bulb?

With plaster of Paris or cement. The rib *i* around the neck of the bulb, Fig. 399, prevents the glass from pulling out from the base.

1176. How much light does an incandescent lamp give?

From ½ to 100 candle-power, and even more, according to the size of the filament. The smallest sizes are used only for special purposes, such as the decoration of rooms and the investigation by physicians of throat and nose conditions. The largest sizes are used for illuminating large rooms, halls, etc.

1177. In what sizes are incandescent lamps most generally used?

The common sizes are 8, 16, 32 and 50 candle-power, the standard size of filament lamp being 16 candle-power.

1178. Are there other kinds of incandescent lamps in common use besides those just described?

Yes. Besides the lamp with a cellulose or carbon filament, there is an incandescent lamp constructed exactly the same,

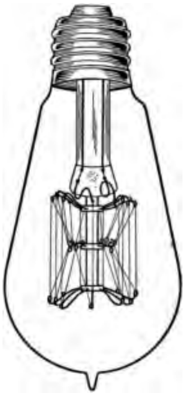

Fig. 401.—Tantalum Filament Lamp.

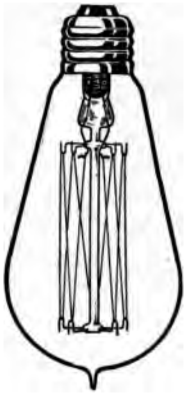

Fig. 402.—Tungsten Filament Lamp.

except that it has a metallized carbon filament; it is called the Gem lamp, and the metallization of the carbon filament is produced by heating the ordinary treated carbon in an electric furnace to a very high temperature. In addition to this are the metallic filament lamps, in one type of which the metal tantalum found in Europe is used for the filament, and in another type the metal tungsten which is produced in this country is used. As the methods of mounting these filaments differ somewhat from the method employed for the carbon and metallized carbon filaments, they are shown in Figs. 401 and 402, the former representing the tantalum lamp and the latter the tungsten lamp.

1179. What is the object in making filaments of metal?

The metal filaments are much more efficient than the carbon filament; that is, they give more candle-power for each watt of electrical power.

1180. How do the efficiencies compare?

The efficiency of the present carbon filament requires about 3 watts per candle-power of light; the corresponding Gem lamp with its metallized carbon filament requires 2.5 watts per candle-power; the tantalum filament requires about 2 watts per candle-power, and the tungsten filament about $1\frac{1}{4}$ watts per candle-power.

1181. If tantalum and tungsten lamps are so much more efficient than carbon lamps, are they not rapidly replacing them?

Tantalum lamps were placed on the market in 1906, and tungsten lamps a few years later. At first, their filaments gave considerable trouble on account of their brittleness, especially where there was vibration; in addition, sudden jars and rough handling dislodged the filament from its mounting and caused the loops to become tangled. Tantalum and tungsten lamps also cost considerably more than carbon lamps of equal candle-power, so that until quite recently the carbon lamp has held its own, but is now being rapidly replaced by the tungsten lamp, which through improvements in toughening the filament and mounting it more securely has triumphed over the tantalum lamp as a competitor of the carbon.

1182. Why are metal filaments different in shape and mounting from carbon filaments?

Owing to the comparatively low specific resistance of tantalum and tungsten filaments, they must be made longer than carbon filaments in order that the total resistance of the filament be high enough. This necessitates mounting the metallic filament upon spiders, each comprising a number of small hooks radiating from a glass support. The filament is loosely wound back and forth over these hooks so as to form

loops about 1 inch long in the tantalum lamp (see Fig. 401) and about 2 inches long in the tungsten lamp (Fig. 402).

1183. How long a time does the filament of an incandescent lamp last?

All of the filaments mentioned will last a long time if not subjected to jars or excessive vibration, but as the candle-power decreases with the length of service life, the so-called useful life is much shorter than the possible mechanical life. Up to the point where the candle-power becomes reduced 20 per cent. (one-fifth of the original candle-power), the carbon filament has a life of from 400 to 500 hours, the metallized carbon filament about 600 hours, the tantalum filament about 800 hours on direct current or 600 hours on alternating current, and the tungsten filament about 1000 hours on either current.

1184. As the filaments are in vacuum and cannot burn, why do they give out?

They are weakened mechanically by the expansion and contraction due to the enormous rise of temperature when lighted and the corresponding drop when the current is cut off. There is also a slow reduction in the thickness of the filament due to minute particles becoming detached from the surface and deposited on the inner surface of the glass bulb by a sort of electrostatic action.

1185. Which of the incandescent lamps most closely approach daylight in color values?

The tungsten lamp, which by test gives 34 per cent. of daylight color. The tantalum gives 27 per cent., the metallized carbon 25 per cent. and the carbon 22 per cent.

1186. For what voltages are the usual types of incandescent lamps made?

Lamps for ordinary illumination are made for voltages ranging from 27 to 125 volts, but those most used are for 100 to 125 volts, because that is the standard range of lighting circuits.

1187. How are incandescent lamps connected in circuit? It will be observed from the lamps shown that the bases

Fig. 403.—Key Socket, shown Dissembled at the Left and Assembled at the Right.

are alike in construction and all of them will therefore fit the same socket. Except for a variation in size, all incan-

Fig. 404.—Pull Socket, showing Interior and Exterior Views.

descent lamp bases in common use are made as shown, and are called Edison bases. The socket into which the lamp base

screws serves to bridge the gap between the lamp leads and the lamp and provides a means of introducing a switch in circuit for turning on or off the current through the lamp. The switch usually takes the form of a key, as shown in Fig. 403, but sometimes of a chain, as in Fig. 404, consecutive pulls on the chain alternately opening and closing the circuit.

1188. Show the inner construction of the key socket and explain how the key works.

Comparing the dissembled view of the key socket in Fig.

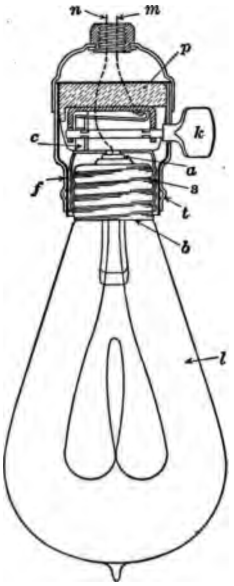

Fig. 405.—Sectional View of Key Socket, showing its Construction and Connection with the Lamp.

403 with the sectional view in Fig. 405, where corresponding parts are lettered the same, it will be seen that *p* represents a porcelain block which serves as a foundation upon which the various parts are mounted; *k* is the key; *s* the brass threaded contact shell; *b* the lamp base; *l* the lamp; *f* a fiber lining which insulates the outer socket shell *t* from the

inner contact shell *s*; *a* the contact spring to which the lamp lead *n* is connected and which, when the lamp is screwed tightly in the socket brings *n* in connection with the center contact on the base of the lamp and consequently with one of the leading-in wires to the filament; and *c* is the key contact which, when in the position shown, brings the lamp lead *m* in connection with the contact shell *s*, thence in contact with the remaining leading-in wire to the filament and so

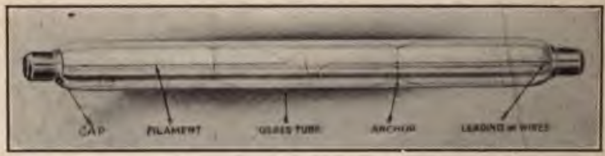

Fig. 406.—J-M Linolite Lamp.

completes the circuit through the lamp. When the key *k* is turned at right-angles to its present position, *c* no longer makes contact with *s* and the lamp circuit is open.

1189. Are there any special forms of incandescent filament lamps that do not fit an Edison socket?

There is one called the J-M Linolite lamp, which is quite extensively used in desk, show window, bulletin board, picture and show case lighting, that requires a special socket.

Fig. 407.—Reflector containing Three J-M Linolite Lamps.

This lamp, which is made by the H. W. Johns-Manville Company, is shown in Fig. 406 and consists of a glass tube about one foot long and one inch diameter, through which a carbon or tungsten filament runs that terminates in metal caps at the ends, the caps forming the terminals of the lamp. It is made in 16, 20 and 28 candle-power, and when a number of lamps are mounted end to end in a suitable aluminum reflector, as in Fig. 407, there results a practically continuous

line of light of any desired length. The sockets are simply spring clips, in which the metal terminal caps fit. The connecting wires from the mains are led along inside the reflector, where they are attached to the spring clips and current is thereby supplied to the filaments for lighting them.

1190. How do incandescent filament lamps compare with other electric lamps as regards their adaptability to general conditions, care, etc.?

Filament incandescent lamps require practically no attention, except to wipe off the dust that naturally accumulates on the bulbs and cuts down their brilliancy. They and their sockets are as near fool-proof as it is possible to make an artificial illuminant, and if the lamps are replaced by fresh ones when they have served the number of hours given in Answer 1183 as their useful life, after which they gradually decline in candle-power, they will be found to give general satisfaction. Occasionally a filament may break, due to rough handling or old age, and then, of course, a new lamp is necessary.

As compared with arc lamps and other illuminants, the incandescent filament lamp requires less attention, having no electrodes to be renewed, gives a more agreeable light, creates no gas, consumes no air and causes no dirt. It burns steadily and evenly and is adapted to all positions and conditions. Its light is also more susceptible of concentration and direction. Large tungsten filament lamps in diffusing globes are rapidly displacing the arc lamps for general illumination of interiors, and to some extent are displacing them in exterior lighting. When all costs are considered—installation, maintenance and current—the expense is about the same in both cases.

1191. Why do some incandescent lamp bulbs have a frosted surface?

To reduce the glare and more equally distribute the light. These advantages are gained, however, at the expense of light intensity and useful life.

1192. How is a lamp bulb frosted?

Either by sandblasting or acid etching. The acid method is the one more commonly used. The mixing of the etching paste is comparatively simple, but as it is dangerous to handle and difficult to secure good results, the frosting is best done by the manufacturers, who will furnish frosted bulbs instead of clear glass ones at a slight advance in price.

1193. How are colored lamp bulbs made?

Either of clear glass superficially colored or of natural colored glass. The former have a dipping or coating of color applied to their exterior surface, in which case the color is not weatherproof; the latter are made from a permanently colored glass, and the color on these is weatherproof.

Fig. 408.—Nernst Lamp and Globe removed from Holder.

NERNST LAMP

1194. Are there any other forms of incandescent lamps besides the filament types previously described?

Yes. The one most closely related to the filament lamp is the Nernst lamp, shown in Fig. 408.

1195. How is the light produced?

By heating a high-resistance conductor in very much the same way as in the filament lamp.

1196. What is the quality of the light given by the Nernst lamp?

It gives a soft white light particularly well adapted for general illumination and decorative lighting.

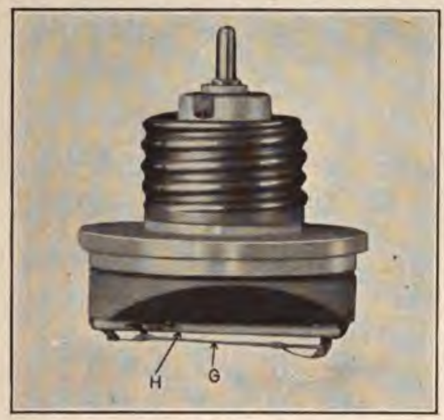

Fig. 409.—Burner of Nernst Lamp in Fig. 408.

1197. What are the principal parts of a Nernst lamp?

The glower, heater, ballast and cut-out.

1198. What is the glower?

The glower is the conductor which is heated white-hot. It is shown at *G* in Fig. 409.

1199. Of what is the glower made?

It is composed of earthy oxides, such as thorium, zirconium and yttrium, mixed with suitable binding material.

1200. How is the glower formed?

The pasty mixture of oxides and binding material is forced

through a die into the form of a small white porcelain-like tube, ranging in outside diameter from 1/64 to 1/16 of an inch and in lengths of ½ to 1½ inches. The tube is then baked to make it strong mechanically, and is finally cut to the proper length for the voltage to be used and closed at the ends. Platinum terminals are attached to the ends of the glower tube, after which a coat of oxides is put on as a protective covering against oxidation.

1201. **What is the life of the glower of the Nernst lamp?**

About 600 hours on direct current, 400 hours on alternating current of 25 cycles, and 800 hours on alternating current of 60 cycles and higher frequencies.

1202. **What is the purpose of the heater?**

To raise the temperature of the glower, at starting, and thereby reduce its resistance. At ordinary temperatures the glower is of such high resistance that it is practically an insulator, but the resistance drops greatly when heated to a high temperature. To accomplish this the heater is mounted close above the glower, as shown at *H* in Fig. 409.

1203. **How is the heater made?**

Of fine platinum wire wound on a round cement-coated rod, which is mounted on a flat porcelain base. The rod is bent so that its several sections lie parallel to the glowers, and in this form is called a "wafer" heater.

1204. **Describe the construction of the ballast and the purpose it serves.**

After the temperature of the glower is raised by the heater until its resistance decreases enough to allow an appreciable current to flow, the heating effect of the current causes the resistance to continue decreasing, and thereby allows the current to increase. When the normal operating point is reached, the decrease in resistance becomes so rapid that unless a steadying resistance, or "ballast" as it is called, is used in series with the glower, the latter would soon burn out. The "ballast" conductor increases in resistance as its tempera-

ture increases and so counteracts the decrease in the resistance of the glower beyond the normal working point.

1205. How is the ballast made?

It consists of fine iron wire mounted in a small glass tube about an inch in diameter and 2 to 3 inches long, containing hydrogen. The reason for this arrangement is that the iron

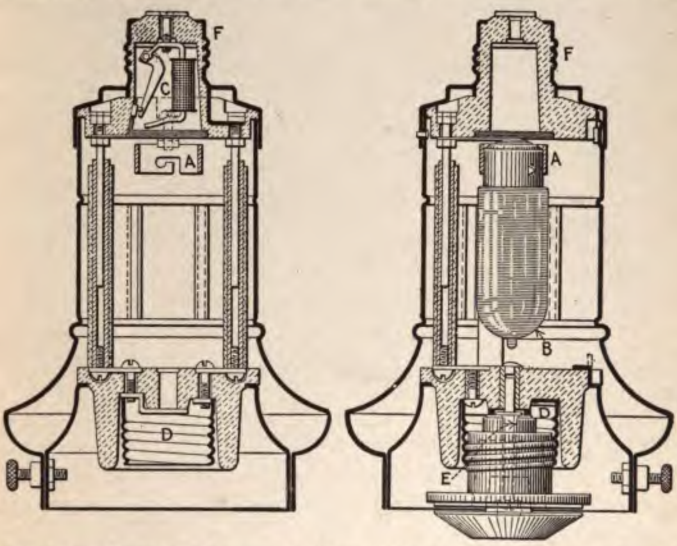

Fig. 410.—Sectional Views of Nernst Lamp Holder containing Cut-Out and Ballast.

wire is kept at a very high temperature and must therefore be protected from the air to prevent oxidation and too rapid temperature changes. The ballast tube is mounted as shown at *B*, Fig. 410.

1206. Why is hydrogen gas used for the ballast in preference to other gases?

Because it will not attack the iron and is a very good conductor of heat.

1207. Why is iron used for the ballast conductor?

Because it is almost the exact opposite of the glower in

temperature characteristic; that is, its resistance rises as the temperature is increased and at almost the same rate as that at which the resistance of the glower decreases throughout the range of the operating temperature.

1208. For what purpose is the cut-out used?

As soon as the glower begins to take current, the current keeps the temperature up and the heater is not needed. In order to prevent deterioration of the heater and unnecessary

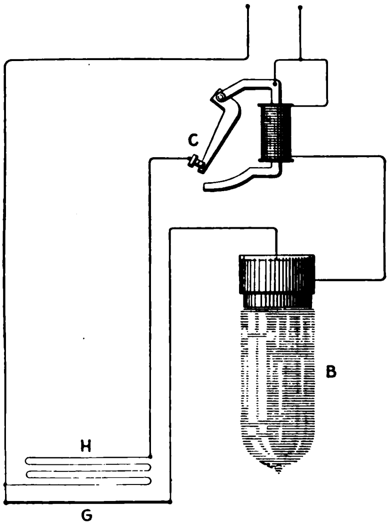

Fig. 411.—Diagram of Nernst Lamp Circuits.

loss of power, the automatic cut-out is provided to disconnect the heater from the circuit.

1209. How is the cut-out arranged?

An electromagnet with a movable armature is mounted, as shown at *C*, Figs. 410 and 411, and the armature is held by gravity in the closed position when not attracted by the magnet. The winding of the magnet is connected in series with the glower and therefore the magnet becomes energized as soon as current begins to flow through the glower; then it

attracts the armature and opens the circuit through the heater.

1210. In what sizes are Nernst lamps made?
They are rated at 66, 88, 110 or 132 watts.

Fig. 412.—Nernst Lamp, Complete.

1211. How much light is given by these different sizes in comparison with that of a 16-candle-power carbon-filament lamp?

The 66-watt lamp is equivalent in illuminating power to three 16 candle-power filament lamps, the 88-watt lamp to four, the 110-watt lamp to five and one-half and the 132-watt lamp to seven.

1212. **Explain the parts of the Nernst lamp shown in Fig. 410.**

In this drawing the socket shown at *A* takes the fitting on the end of the ballast tube *B;* the automatic cut-out is located at *C,* the glower socket at *D* and the heater terminal contact at *E.* The screw plug F fits in the standard Edison lamp socket. The structure shown in the two views in Fig. 410 in section is the upper part of the complete lamp shown in Fig. 412.

COOPER HEWITT LAMP

1213. **Are there any other forms of incandescent lamp?**

Yes; there is one more general class known as vapor-tube lamps. Fig. 413 shows the Cooper Hewitt direct-current mercury vapor lamp, which is one of this class.

1214. **Describe the construction of the mercury vapor lamp.**

It comprises a clear glass tube *N* about an inch in diameter and from 20 to 50 inches long, in which is a small quantity of mercury. This tube, like the filament-lamp bulb, has the air pumped out and is sealed. The mercury is held in the iron cup *C* at the right end of the tube and serves as the positive electrode. The negative electrode is in the glass bulb *A* at the left end of the tube. Platinum wires sealed in the glass carry the current to the electrodes. The current passing from one electrode to the other vaporizes some of the mercury, and it is this vapor which emits the light. The inner surface of the reflector *S* is finished in smooth, white porcelain.

The part *M*, shown separately in Fig. 414, contains two induction coils *N* and *L*, and an adjuster resistance *B* by means of which the current is regulated according to the voltage of the supply. For lamps connected in series, a shunt resistance *T* and a cut-out *O* are also included. The binding

Fig. 413.—Cooper Hewitt Mercury Vapor Lamp.

posts *X* and *Y* are for the leads to the tube, and the binding posts *P* and *F* are for connection to the supply wires.

1215. How is this lamp lighted?

By closing the switch controlling the circuit and then pulling down the chain *R*, Fig. 413, attached to the left end of the holder. This tilts the tube and pours the mercury out of the cup *C* along the tube. The stream of mercury is thus momentarily made to connect the electrodes and the breaking of this continuous stream lights the lamp. When the chain is released, the tube and reflector return to their normal

position by reason of the greater weight at the right end in the iron cup *C*.

1216. Is no provision made for automatically relighting this lamp in case of an interruption of the current supply?

Provision for automatic relighting is made only in the automatic type of Cooper Hewitt direct-current lamp shown

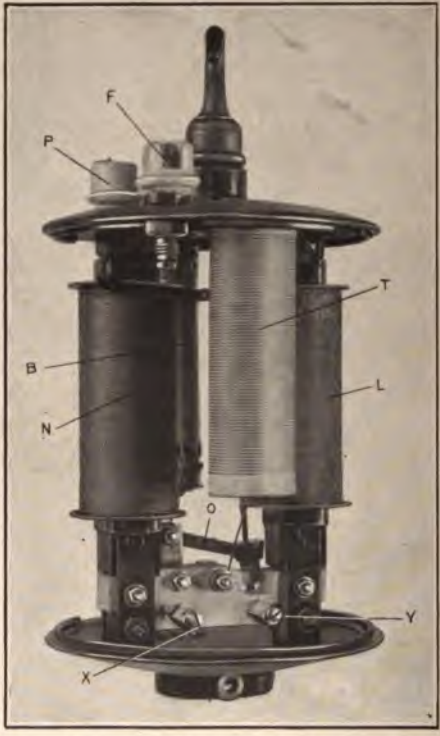

Fig. 414.—Mechanism of Mercury Vapor Lamp in Fig. 413.

in Fig. 415, the tilting being here accomplished by means of an electromagnet in the part *D*. When the circuit is closed through this lamp, the current flows through the electromagnet which tilts the tube for lighting. This auto-

matic tilting is desirable in places where it would be difficult to reach the chain by hand; and it also insures the relighting of the lamp in case there is a momentary interruption of the current supply.

1217. In the lamp shown in Fig. 415, are the two tubes connected in series or parallel?

In series.

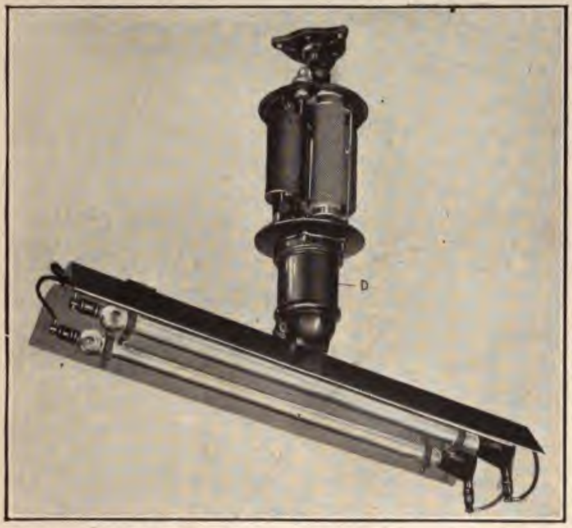

Fig. 415.—Double-Tube Mercury Vapor Lamp.

1218. What is the rated candle-power and what the efficiency of the lamp shown in Fig. 413?

The candle-power is 300 and the efficiency is 0.64 of a watt per candle-power.

1219. Is the mercury vapor lamp made for alternating-current circuits?

Yes. The mercury vapor lamp for alternating-current circuits differs somewhat from the direct-current lamp. The principal difference is in the auxiliary part, which contains a transformer for supplying the proper voltage to the tube

electrodes, two choke coils, a shifter consisting of a small glass vessel fitted with two electrodes and containing a small quantity of mercury for lighting the tube, and the shifter resistance.

1220. How often must the glass tubes of mercury vapor lamps be renewed?

After about 3750 hours of service.

1221. What kind of light does the lamp give?

A greenish-colored light which has great penetrating power. It enables printed matter to be read with unusual ease and brings out with great clearness the fine markings on steel rules, and small scratches and defects on other bright metals.

MOORE LAMP

1222. Is there any other form of vapor-tube lamp?

Yes. The Moore lamp shown in Fig. 416 is classed as a

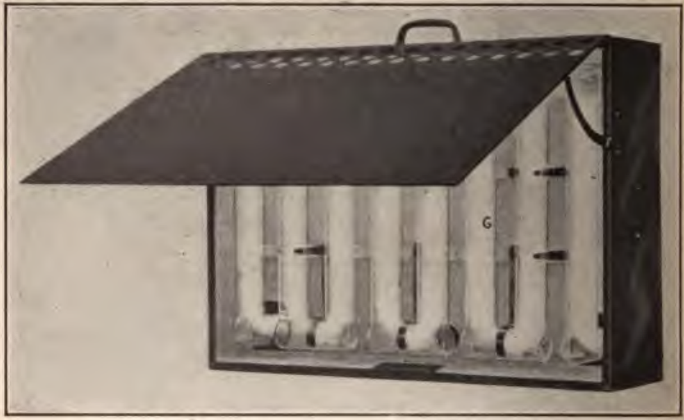

Fig. 416.—Moore Vapor-Tube Glow Lamp.

vapor lamp because light is produced in it by passing an alternating current through carbon dioxide gas contained in a glass tube from which the air has been pumped out.

1223. What kind of light is given by the Moore lamp?

A clear, white light of about 200 candle-power, possessing

practically the same color values as natural daylight. The Moore light is therefore particularly advantageous in matching colors at night or during dark days.

1224. Does the carbon dioxide gas become exhausted?

It does, and for this reason there is a compartment behind the glass tube *G*, Fig. 416, containing the gas which is fed automatically by means of an electric valve into the tube

Fig. 417.—Straight-Line Moore Tube installed in Factory.

as it is needed. The carbon dioxide in the compartment has to be renewed after about 1000 hours of service. On account of a deposit gradually forming in the tube *G*, the tube also has to be renewed after 4000 or 5000 hours of service.

1225. How much current does the 200 candle-power Moore lamp require?

At 110 volts it requires 23 amperes; at 220 volts, $11\frac{1}{2}$ amperes.

1226. Is this lamp made in any other form than shown in Fig. 416?

Yes; for the general illumination of large areas the glass tube, instead of being arranged in gridiron fashion, as in Fig. 416, is straight and intended to be hung from the ceiling, as in Fig. 417, or made a part of the cornice. In this form it gives " line " instead of " spot " lighting. If nitrogen gas instead of carbon dioxide gas be used in the tube, a yellow light can be produced instead of a white light.

ARC LAMPS

CARBON ARC LAMPS

1227. **How is light produced in an arc lamp?**

By passing current through two carbon rods held in line with each other, and with adjacent ends a short distance apart. The current bridging the gap between the carbons produces a brilliant arc which gives to the lamp its name.

1228. **Does the arc produce all the light given off?**

No; the greater portion of light comes from the ends of the carbon rods, which become white-hot under the influence of the current.

1229. **Is direct current or alternating current used?**

Some arc lamps work with direct current, and others with alternating current.

1230. **Does not the current burn off the ends of the carbons?**

Yes; the ends are slowly burned away. The length of the positive carbon is reduced much more rapidly than that of the negative carbon in a direct-current lamp with an unshielded arc.

1231. **Why does the positive carbon burn more rapidly than the negative?**

Because a greater portion of it is heated to a higher temperature and oxidation is therefore more rapid. Some of the particles of carbon detached from the positive rod are carried across the arc by the current flowing from the one rod to the other and are deposited on the tip of the negative rod, replacing an equal quantity of carbon particles burned off by the arc.

1232. **Does the action of the current mentioned in An-**

swer 1231 have any other effect besides the difference in the rates of shortening the two rods?

Yes; the flow of current from the positive to the negative carbon hollows out the end of the positive rod, and the deposit on the end of the negative carbon builds up that end into a sort of peak, as indicated in Fig. 418. The arc eats away the edge of the negative carbon tip and gradually undermines the peak, which breaks off. A new peak is then

Fig. 418.—Appearance of Carbon Rods in Arc Lamp during Operation.

formed gradually and later broken off, and so on, until the rod is consumed.

1233. Which carbon furnishes the greater portion of the light given off?

The positive carbon, which has the hollowed end, or crater, as it is called.

1234. Is the positive carbon in the lamp placed above the negative one, as shown in Fig. 418?

Yes, usually; in order that the intense light from its crater may be cast downward, where it is most needed.

1235. What is the color of the light from an arc lamp?
The color of the light depends upon the composition of the carbon rods. If there are impurities in the carbon, the color will vary considerably. Ordinarily, the light is tinged with violet but is very brilliant, closely resembling sunlight.

1236. How much light does an ordinary arc lamp give?
There are two common sizes of open arc lamps rated respectively at 1200 and 2000 candle-power. These ratings are never realized in actual illumination; they are merely nominal. The actual mean spherical candle-power, that is, the average value of the intensity of light thrown out in all directions from the arc, is from 375 to 450 candle-power in the open lamps where the arc is not protected from the surrounding air, and from 150 to 300 candle-power in enclosed arcs, according to the kind of current used and its value, being less with alternating than with direct current.

1237. How much current is required by the ordinary direct-current arc lamp?
Direct-current arc lamps in which the arc is not protected from the surrounding air require 6.8 amperes in the 1200 candle-power size, and the 2000 candle-power lamp takes 9.6 amperes.

1238. What voltage is required to force the current in Answer 1237 across the arc?
Approximately 46 volts. This includes about 3 volts to overcome the resistance of the carbons and about 3 volts more to overcome the resistance of the lamp magnet and connections, leaving about 40 volts applied to the arc itself.

1239. How long will the carbons in an arc lamp burn before they have to be renewed?
The rate of consumption depends largely upon whether the arc is "open" (not shielded), as in Fig. 419, or enclosed as in Fig. 420. In the former case the arc is freely surrounded by air and burns the carbons rapidly; in the latter it is enclosed in a small inner glass globe that practically ex-

cludes the air, and the consumption is therefore much slower owing to the restriction of oxygen in the inner globe. The rate of consumption for an open arc ranges from 1 to 2 inches of positive carbon per hour; the rate for an enclosed arc ranges from 0.07 to 0.10 inch per hour. The rate de-

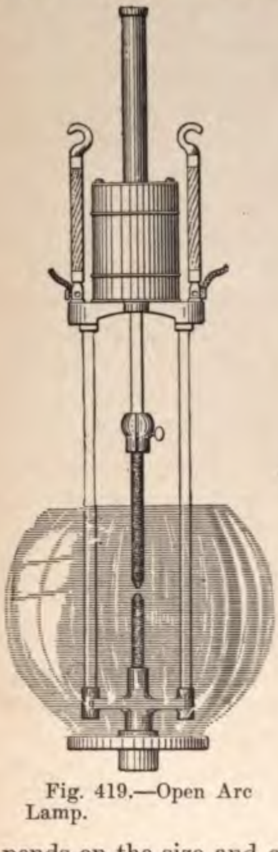

Fig. 419.—Open Arc Lamp.

Fig. 420.—Enclosed Arc Lamp.

pends on the size and composition of the carbon rods and the character of the current—whether direct or alternating.

1240. In enclosed arc lamps, is the inner glass globe perfectly air-tight?

No; because the cap at the top of the globe is provided

with a hole in the center through which the upper carbon can move freely. The downward movement of the upper carbon is necessary in order that the proper distance may be maintained between the carbon tips to form the arc. The fitting at the top and bottom of the inner globe is very snug, however, and but little air can get in.

1241. **Does the enclosed arc possess any advantages over the open arc besides the lower rate of carbon consumption?**

Yes; the light of the enclosed arc is much softer and steadier than that of the exposed arc and in consequence is much preferable for interior illumination. Comparing Fig. 419 with Fig. 420, it will be seen that the large outer globe used on the open arc lamp is also used on the enclosed arc lamp, in addition to the small inner globe which encloses the arc. This makes the fire risk from sputtering carbons considerably less with the enclosed arc lamp than with the open one. On account of the slower carbon consumption in enclosed arc lamps, the cost of carbons and of replenishing is less. To offset this in a measure, however, are the first cost and maintenance of the inner globes and the additional labor of keeping them clean. Taking everything into consideration, the enclosed arc lamp is almost always preferable to the ordinary open arc lamp; it has practically superseded the open arc for indoor lighting and is rapidly replacing it for outdoor service.

1242. **Do the ends of the carbons in an enclosed arc lamp burn to the same shapes as those of an open arc?**

No; the ends of the carbons in an enclosed arc lamp burn almost flat, as shown in Fig. 421. This is due to the fact that the carbons are separated further, which causes the arc, instead of maintaining one position, to shift continually over the ends of the carbons.

1243. **Are arc lamps operated with alternating current different from the others?**

Yes; arc lamps are made especially for that kind of current.

1244. What effect does the alternating current have upon the carbons?

It causes both carbons to become equally luminous, and both of them are consumed in about the same time. In the alternating-current enclosed arc lamp, the upper and lower carbons are at about the same temperature when the lamp is burning, in consequence of which more light is thrown upward than with the direct-current arc. The appearance of the carbons is similar to that shown in Fig. 421, but the ends are more

Fig. 421.—Appearance of Carbon Rods in Enclosed Arc Lamp during Operation.

flat because the arc travels around the ends of the carbons even more frequently than in the case of an enclosed direct-current arc lamp.

1245. How are arc-lamp carbon rods made?

Those for open arc lamps are composed chiefly of petroleum coke, pulverized and mixed with tar, or a similar binding material, and molded into rods. The rods when dry are baked at a high temperature. Carbons for enclosed arc lamps of both direct-current and alternating-current types must be made of a much finer quality of carbon because the impuri-

ties become vaporized and deposited upon the inner glass globe, reducing its transparency. Lampblack, which is practically pure carbon, is therefore employed. For this reason, and also because they must be perfectly straight and of uniform diameter so they will pass easily through the hole in the cap of the enclosing globe, these carbons cost considerably more than the carbons used in open arc lamps.

Carbons for alternating-current arc lamps are generally cored; that is, the carbon rod is formed with a small hole extending through the center of the rod and this is filled with a much softer grade of carbon than the main tubular portion. In some alternating-current lamps, cored carbons are recommended for both the upper and lower rods, while in others they are used only for the upper rod.

1246. Why are arc-lamp carbons sometimes plated with copper?

Carbon rods used in open arc lamps are usually given a thin coating of copper to increase their conductivity and make them burn more evenly and for a longer time.

1247. How many kinds of arc lamps are there?

Four general types, namely: constant-potential lamps for operation in parallel on direct-current circuits; constant-potential lamps for parallel operation on alternating-current circuits; constant-current lamps for series connection on direct-current circuits; constant-current lamps for series connection on alternating-current circuits. The only essential difference between these four types is in the construction and operation of the mechanism.

1248. For what purpose is the mechanism needed?

To control the relative positions of the positive and negative carbons.

1249. How does the mechanism control the positions of the carbons and why is this necessary?

The carbons must first be in contact with each other, to allow the current to flow through the lamp; then they must

be separated slightly to form the arc between their ends. As the ends waste away, the gap between them must be adjusted so as to keep the length of the arc about the same throughout the burning period. The mechanism performs the two operations of "striking" the arc when the lamp is first put into the circuit and then regulates the length of the arc during its activity.

1250. How far apart should the carbons be separated?

For currents up to $5\frac{1}{2}$ amperes, which is the usual limit of constant-potential enclosed arc lamps, the separation should be from 3/32 to 3/16 of an inch. For 6 to $7\frac{1}{2}$ amperes, usual with constant-current enclosed arcs, the separation is from $\frac{1}{8}$ to $\frac{1}{4}$ of an inch.

1251. Explain the operation of the constant-potential direct-current arc lamp.

Referring to Fig. 422, which is a diagrammatic view of a lamp of this type, *M* and *M* represent the two coils of a plunger-type magnet which is provided with a U-shaped armature *A*, consisting of two plungers joined by a yoke. The coils are connected in series with each other and with the brass tube *B* which holds the upper carbon; therefore, the current entering the lamp at *P* passes through the magnet coils *M M* to the tube *B*, thence down through the carbons and the wire *n* to a sliding contact *F* on the resistance coil *R* and out at the binding post *N*.

When current is first turned on, the magnet coils lift the armature *A*, which slides on the tube *B*. The upward movement of the armature causes a clutch *C*, which is linked to it, to raise the upper carbon rod and "strike" the arc. As the upper carbon is lifted away from the lower one, the arc lengthens and its resistance therefore increases; thereupon the current decreases, weakening the magnets, until a point is reached where the weight of the armature and the carbon is just equal to the upward magnetic pull on the armature.

As the lamp continues to burn, the carbons become shorter, thereby increasing the length of the arc and reducing the

current, which weakens the magnetic pull on the armature; the latter therefore drops until the resistance of the arc becomes normal, when the magnetic pull again balances the weight of the moving parts.

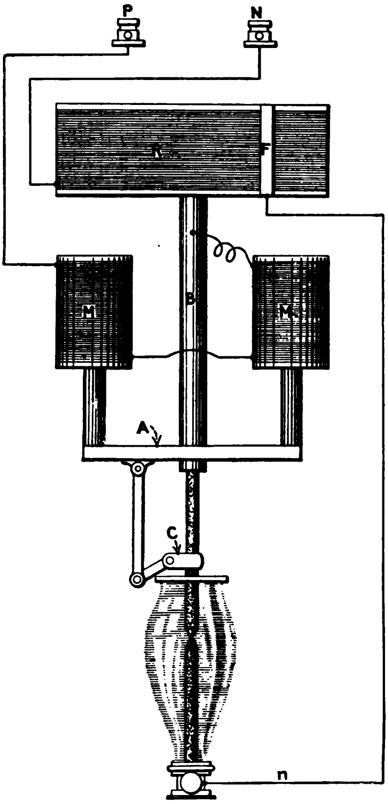

Fig. 422.—Diagram of Constant-Potential Direct-Current Arc Lamp.

1252. **Does the armature drop suddenly in adjusting the arc?**

No; the "feeding," as it is called, is made very gradual by attaching a dash-pot to the armature, and thereby preventing any sudden movement or see-sawing.

1253. Show the actual arrangement of the parts of the constant-potential direct-current arc lamp illustrated diagrammatically in Fig. 422.

Fig. 423 affords an idea of the mechanism. The magnet coils are shown at *M* and *M;* they are wound on brass spools

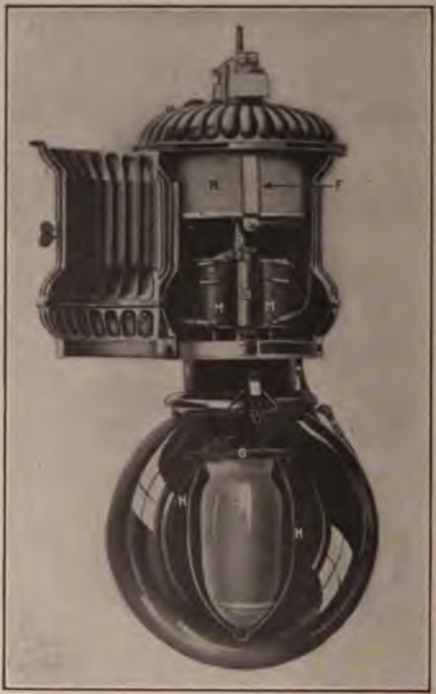

Fig. 423.—Constant-Potential Direct-Current Arc Lamp.

which are attached to the central tube *B*. The resistance coil is shown at *R* and the sliding contact at *F*.

1254. What is the reason for using the resistance coil and sliding contact?

To take up the excess voltage of the circuit, to steady the arc and to provide means for adjusting the voltage at the arc. The sliding contact *F* cuts more or less of the resistance

coil into the circuit; the more of the coil there is cut in, the less will be the voltage at the arc, because of the increased drop in the coil.

1255. **Why is it necessary to adjust the voltage at the arc?**

Because constant-potential circuits are not all of exactly the same voltage, even when rated the same. The actual voltage of a so-called 110-volt circuit may be anywhere from 105 to 115 volts, or even 120. As the enclosed arc needs about 75 volts, some extra resistance is necessary anyway, and by making this adjustable, the voltage at the arc can be made normal no matter what the actual circuit voltage may be.

1256. **How does the resistance coil steady the arc?**

By the increase in the voltage drop in it when the current through it increases. An increase in the current flowing through the arc would decrease the resistance of the arc because the larger current increases the cross-section of the arc and also decreases the resistance of the carbon particles in the arc. A decrease in the current flowing through the arc, therefore, would increase the resistance of the arc. Consequently, if the supplied voltage was just equal to that required by the arc, and the arc resistance should be increased by the burning away of the carbons, the current would decrease, causing a further increased resistance of the arc, and this would cause a further decrease of current and increase of resistance, with the ultimate result that the arc would be broken. Likewise, an increase of current causing a decrease in arc resistance would still further increase the current and result in a similar unstable condition.

With the wire resistance in series with the arc and properly adjusted so as to make the arc voltage correct when the normal current is flowing through the lamp, a decrease in the current will diminish the drop through the resistance and, as the line voltage remains constant, the voltage across the arc will increase and compensate for the increase in

resistance of the arc. Likewise, an increase of current causing a larger drop through the resistance will lower the voltage across the arc and maintain equilibrium.

1257. Describe the other important parts of the arc lamp in Fig. 423.

The dash-pot *D* is attached to the armature of the regulating magnet for the purpose described in Answer 1252. The upper end of the top carbon is set in a metal socket which is electrically connected to the central tube *B* by a flexible stranded wire. The inner globe is of clear glass for outdoor service, and semi-transparent so as to diffuse the light for indoor service. It is supported by a spring bail *H* suspended from the cap *G* of the inner globe. An upward projection formed by a few turns of the wire of which the bail is made, rests in a depression in the lower end of the globe and exerts a steady upward pressure which keeps the upper edge of the globe at all points in close contact with the cap *G*.

1258. Is a constant-potential arc lamp for alternating current exactly like the direct-current lamp?

Not quite. The alternating-current lamp is provided with a magnet armature made up of thin sheets of soft steel riveted together, instead of solid plungers fastened to a solid yoke; it is also provided with a " choke " coil instead of the simple resistance coil of the direct-current lamp. Fig. 424 is a diagram of the parts, in which the " choke " coil *Rx* is substituted for the resistance coil *R* in Fig. 422 and the laminated armature *A* is shown.

1259. Why is a " choke " coil used instead of a resistance coil?

Because it wastes much less energy. The coil is in sections wound around a soft iron core which forms a closed magnetic circuit. An alternating current passing through this coil produces a rapidly alternating magnetism in its core which induces a counter electromotive force in the coil. This counter electromotive force serves the same purpose as

the drop in the resistance coil used in the direct-current lamp, but does not absorb any energy. There is some energy loss due to the resistance of the coil, but it is very low because the resistance is extremely small.

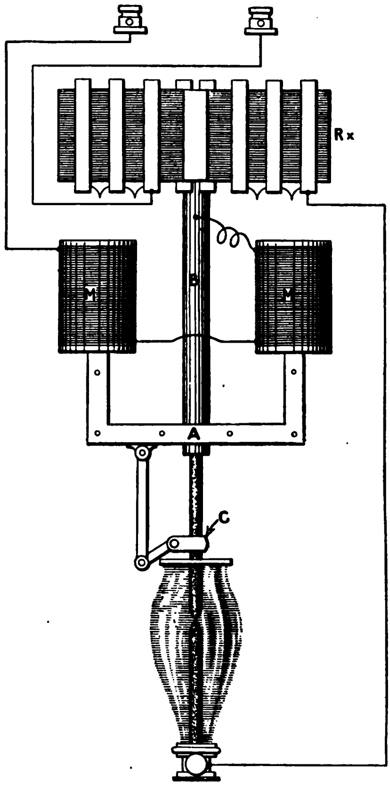

Fig. 424.—Diagram of Constant-Potential Alternating-Current Arc Lamp.

1260. If the choke coil wastes less energy than a resistance coil, why is it not used in the direct-current lamp?

Because direct current flowing through it cannot produce the alternating magnetism in its core necessary to induce a counter electromotive force in the coil.

1261. Illustrate a constant-potential alternating-current arc lamp.

The mechanism is shown in Fig. 425. The general outside appearance is similar to that of the direct-current lamp, Fig.

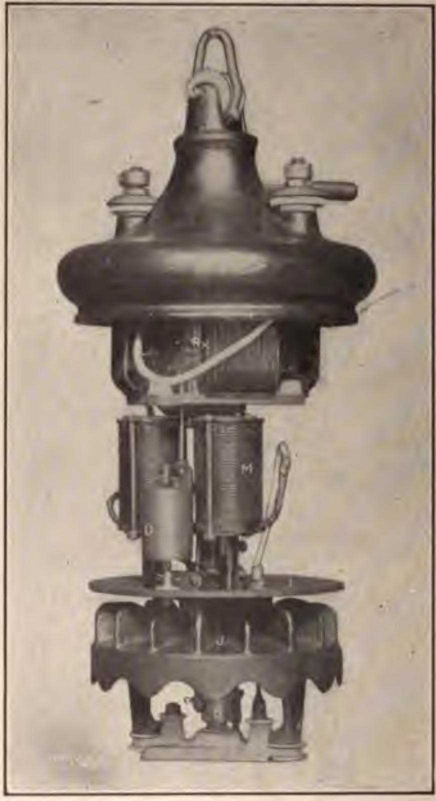

Fig. 425.—Mechanism of Constant-Potential Alternating-Current Arc Lamp.

423. The entire lamp is built around the central brass tube *B*. The top or hood of the case is attached to the upper end, and the floor plate *I* and radiating plate *J* are attached to the lower end of the tube. The choke coil is shown at *Rx;* the other parts are lettered the same as in Fig. 423.

1262. What is the radiating plate for?

To radiate the heat developed by the arc and thereby protect the magnets and mechanism from it.

1263. How is the mechanism of the constant-current series lamp arranged?

A diagram of the mechanism and circuits of this type of lamp for direct current is shown in Fig. 426. Two separate

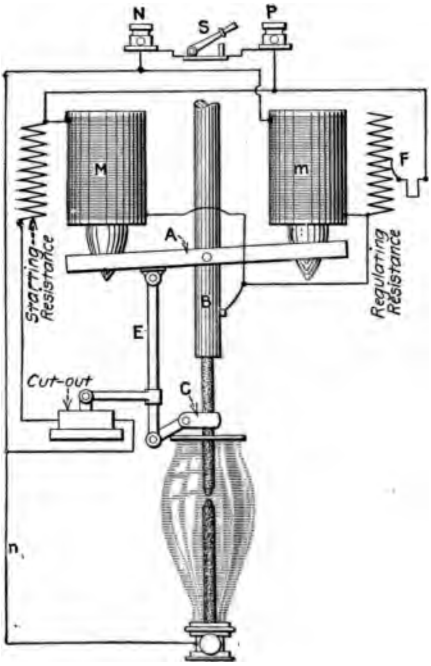

Fig. 426.—Diagram of Constant-Current Series Arc Lamp.

magnets are used, one connected in series with the arc and another connected in shunt to the arc. The series magnet is shown at *M* and the shunt magnet at *m*. The armature *A* in this lamp is pivoted to the central tube *B* instead of sliding on it, and it is tilted one way by the series magnet, to lift the clutch *C* and the upper carbon, and pulled the other way by the shunt magnet to release the clutch and drop the car-

bon. The switch S is used to cut the lamp out of circuit by short-circuiting the terminals.

1264. Explain the operation of the mechanism in Fig. 426.

When the lamp is first put in circuit, the armature A is tilted to the position shown, by the weight of the clutch C and its linkage; the clutch is then open, allowing the upper carbon to rest on the lower one. The current passes from the positive terminal P to the series magnet M, the starting resistance and the regulating resistance, and divides between the three; but most of it goes through the magnet, the carbons and the return wire n, because that path has the lowest resistance. The magnet M lifts the armature and clutch, and the latter engages the upper carbon and carries it upward, striking the arc between the two carbons. As soon as the link E starts upward, it opens the contacts of the cut-out and that part of the current which at first was shunted through the starting resistance now passes through the carbons. As the upper carbon is lifted away from the lower one the lengthening of the arc increases the voltage across the carbons and this increases the strength of the magnet m which is connected in parallel with the carbons; when the arc is at normal length, the pull of the magnet m is sufficient to prevent the magnet M from lifting the carbon any further. As the carbons burn away, the lengthening of the arc shunts more current through the magnet m, and the magnet M is correspondingly weakened; the armature is therefore tilted slightly the other way, lowering the clutch C to the point where it trips and feeds the upper carbon downward.

1265. What is the starting resistance for?

To prevent the cut-out from putting a dead short-circuit across the lamp when it is closed by the extreme downward travel of the link E. Such a short-circuit would make it impossible for the lamp to restart its arc automatically when next cut into circuit.

1266. What is the need for the cut-out?

To close the circuit around the lamp if the upper carbon should hang up or burn so short that it could not be fed downward any further. In either case, the arc becomes excessively long and the magnet *m* pulls its end of the armature up so

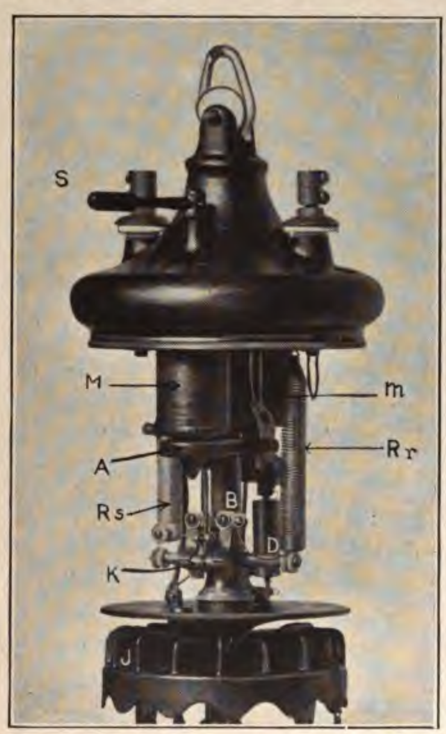

Fig. 427.—Mechanism of Constant-Current Series Arc Lamp.

far that the cut-out is closed and cuts the rest of the lamp mechanism out of circuit.

1267. What is the regulating resistance for?

To adjust the strength of the lifting magnet *M* and thereby regulate the length of arc necessary for the feed magnet *m* to overcome the lifting magnet and feed the carbon. The regulating resistance is in shunt to the series magnet coil and

shunts more or less current out of it, according to the position of the sliding contact *F*.

1268. Illustrate the actual mechanism of the constant-current arc lamp represented by the diagram in Fig. 426.

Fig. 427 shows the mechanism of this type of lamp. The cut-out is shown at *K*, the starting resistance at *Rs* and the regulating resistance at *Rr*. The other parts are lettered the same as in Fig. 426.

1269. Are all constant-current arc lamp mechanisms like the one just described?

Not in all the details, but they all work on the differential principle; that is, a series magnet pulls the carbons apart and it is opposed by a magnet coil connected in shunt to the arc. In some lamps the shunt coil opposes the series coil magnetically instead of mechanically. Magnetic opposition is obtained by winding the series and shunt coils on the same core; any increase in the current in the shunt coil weakens the magnet as a whole, because the magnetizing effects of the two coils are in opposition to each other. In most cases, however, the magnets are separate and their pulling efforts are opposed mechanically, as in the lamp described.

1270. Is the series alternating-current lamp like the direct-current lamp?

Yes; in all essential features, except that the magnet cores and armatures are laminated instead of solid, and choke coils are used instead of resistance coils, as explained in the discussion of constant-potential arc lamps.

FLAME ARC LAMPS

1271. Are there any other types of carbon arc lamp?

Yes; there are two other types, closely related to each other and both known as "flame arc" lamps.

1272. What is the difference between the two types of flame arc lamps?

One is of the open type and the other enclosed; this apparently small difference, however, causes a great difference in

the arrangement of the carbons and the design of th ism which "feeds" the carbons as they are consu the open type both carbons project downward, w

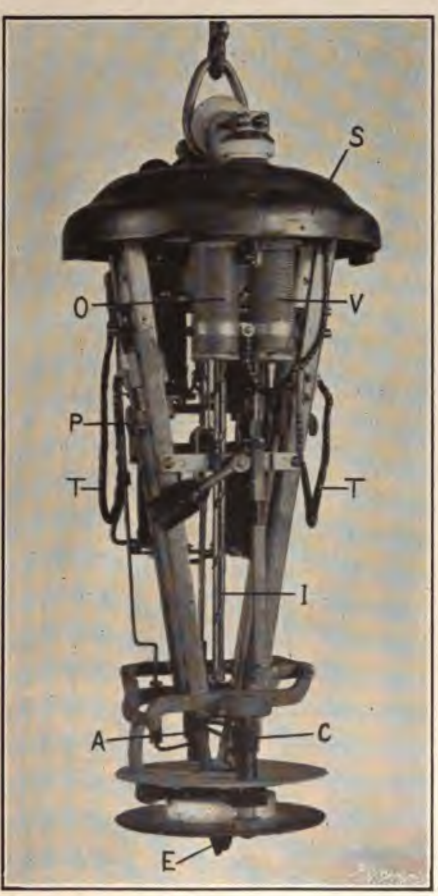

Fig. 428.—Open Flame Arc Lamp.

active ends close together and their mount ends s and both are fed downward. The carbons of the type are arranged end to end, exactly as in the ordi lamp, and the operating mechanism is also very simi

1273. Illustrate and describe an open flame arc lamp.

Figs. 428, 429 and 430 show interior views taken at different points around such a lamp. Upon close inspection of Fig. 428 it will be evident that the carbons *A* and *C* both extend downward at opposite angles with the vertical center line of the lamp, the lower ends nearly touching at *E* when the lamp

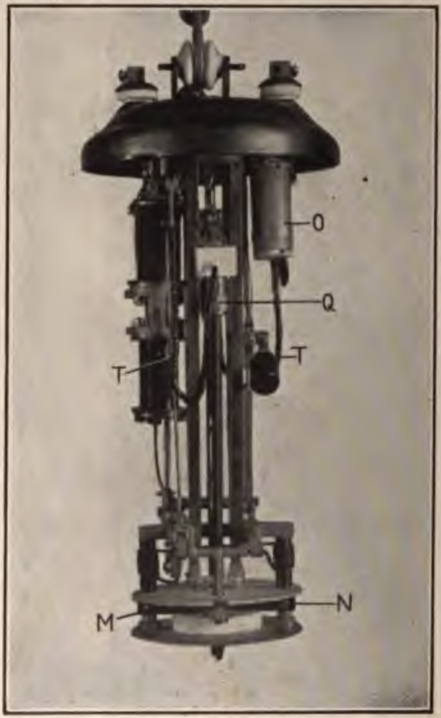

Fig. 429.—Side View of Open Flame Arc Lamp in Fig. 428.

is "dead." The arc is formed between the facing portions of the carbon tips, and to prevent it from creeping up the sides of the carbon rods a magnetic field is provided by magnet poles located at *M* and *N*, Fig. 429.

1274. How do the magnet poles prevent the arc from creeping up the carbons?

The field produced between the poles " blows " the electric arc downward by magnetic repulsion. This causes the arc to curve downward and expand into a sort of flame, as represented in Fig. 431. It is from this that the lamp gets its name.

1275. What is the function of the part shown at D, Fig. 430?

This is a chamber of highly refractory material which sur-

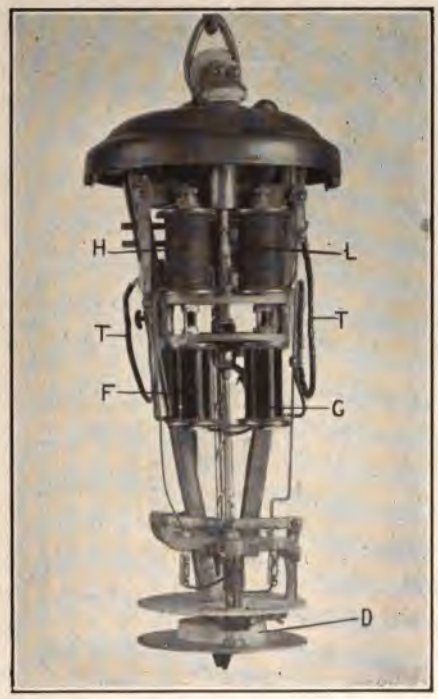

Fig. 430.—Opposite View to that in Fig. 428 of the Open Flame Arc Lamp.

rounds the ends of the carbons and shields them from " washing " of the air currents within the globe. This part of the lamp is called the " economizer " and is necessary on account of the rapidity with which the carbons are consumed.

1276. What is the type of feeding mechanism used?

It is of the differential solenoid type and is shunt starting; that is, when there is no current through the lamp the carbons are apart. When the current is switched on, the shunt coils *F* and *G*, Fig. 430, are first actuated, pulling the carbons into contact and thereby establishing a circuit through the series coils *H* and *L* and the carbons. The series windings then pull the carbons upward, separating the ends and forming an arc, which is thereafter differentially regulated by the shunt and series coils as described in Answer 1269.

Fig. 431.—A "Flame" Arc.

As the carbons burn shorter they are fed downward by means of the central spiral rod *I*, Fig. 428, down which travels a cross-arm that carries the carbon holders *P* and *Q*. The rod *I* is nickeled to insure smooth traveling for the cross-arm, and extends up into the casting *S* where a speed-reducing escapement is located.

1277. What are the objects at T, Fig. 428, which resemble strings of beads?

These are the leads connecting the carbon holders to the circuit; they are insulated by glass beads which are threaded on them.

1278. What is the purpose of the coils O and V, Fig. 428?

They are voltage-reducing and steadying resistances used in series with the lamp when one lamp is connected to a 110-volt direct-current circuit. By using a reactance in place of the resistance, the lamp can be operated singly on 110-volt alternating-current circuits.

1279. What kind of carbons are used in a flame arc lamp?

Cored carbons containing metallic salts and a metallic strip running throughout the length.

1280. What is the nature of the light given by a flame arc lamp?

The metallic salts in the carbons produce a much greater intensity of light than carbon alone and also counteract the tendency to give a bluish or violet light. The light of a flame arc lamp is a brilliant golden yellow.

1281. How long will the carbons burn?

One set will burn about 17 hours with a current of 12 amperes.

1282. What are the advantages of the flame arc lamp over the ordinary arc lamp?

It is much more efficient and the light is far more powerful than can be obtained from the ordinary carbons.

1283. Is there any other kind of arc lamp besides those previously described?

Yes; the metallic flame arc lamp, one of the common forms of which is shown in Fig. 432, is the most efficient arc lamp so far produced.

1284. What voltage is required by the metallic flame arc lamp?

Across the terminals, about 68 volts.

1285. Describe the principal features of the metallic flame arc lamp.

The lamp takes its name from the metallic electrodes used

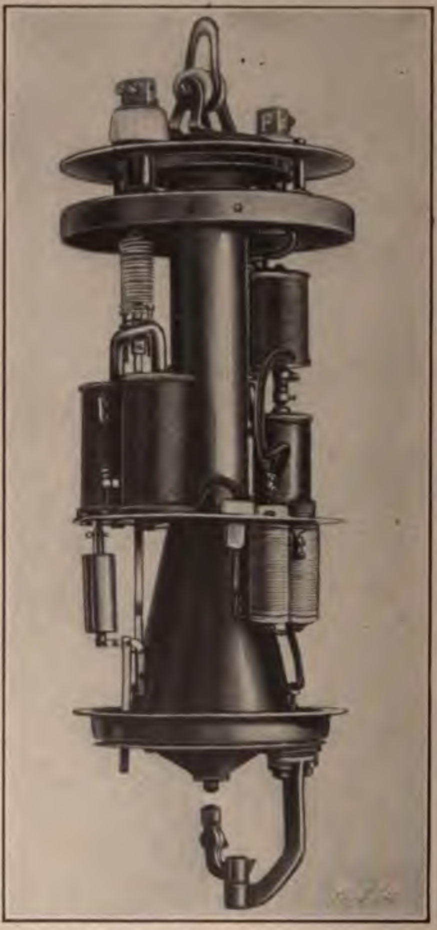

Fig. 432.—Mechanism of Metallic Flame Arc Lamp.

in place of the carbon rods in other lamps. Referring to Fig. 432, it will be evident that the lower electrode is in the form of a button or plug; this is made of copper and is the positive

electrode. The upper electrode is a pencil composed of metallic oxide called "magnetite" and is the negative electrode of the lamp. It is fed downward by a mechanism as it wastes away somewhat as in the case of the ordinary carbon lamp. The positive button is not consumed; hence it is not necessary to use the rod form.

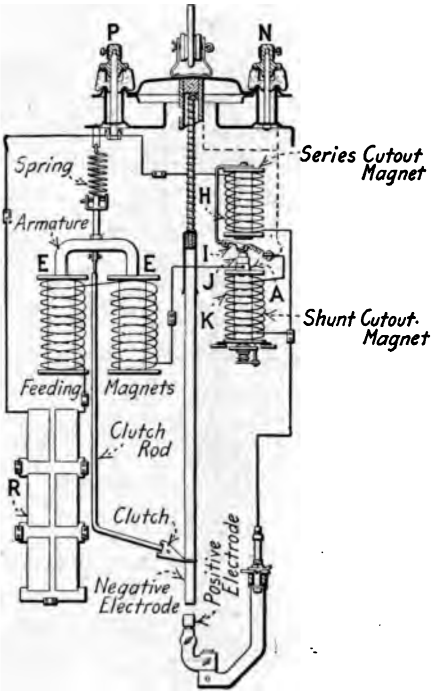

Fig. 433.—Diagram of Mechanism and Circuits in Metallic Flame Arc Lamp in Fig. 432.

1286. Describe how the mechanism shown in Fig. 432 operates.

A diagram of the mechanism and the lamp circuits is shown in Fig. 433. When the circuit to the lamp is closed, the current passes from the terminal *P* through the resistor *R*, the feeding magnets, and the contacts *J* and *I* to the negative

terminal *N*. This energizes the feeding magnets, which pull the cores *E E* downward and thereby lowers the negative rod into contact with the positive button. This contact shunts most of the current out of the feeding magnets, the current passing to the positive button directly through the series cut-out magnet, which lifts its armature *I* and opens the circuit through the feeding magnets. The spring above the feeding magnets then pulls the cores *E E* up again, separating the electrodes and striking the arc.

1287. How does the mechanism control the length of the arc as the rod burns away?

The shunt cut-out magnet *K* is connected across the arc, and when the arc lengthens, due to the burning away of the rod electrode, this magnet becomes strong enough to lift its plunger core with the contact *J* until the latter touches the contact *I*, which was previously lifted by the series cut-out magnet. This restores the circuit through the feeding magnets, which pull the electrodes into contact again, after which the former are cut out of circuit as previously described, allowing the spring to again strike the arc.

1288. Then the arc is put out when it becomes too long, and a new one established?

Yes; the rod electrode does not " float " under the control of the feed magnet as in the carbon arc lamp. The spring pulls the armature up against a stop which is set for the correct length of arc.

1289. What is the reason for placing the negative electrode above the positive?

There are two advantages; the greater portion of the light comes from the flame of volatilized oxide from the negative electrode, and the length of the negative electrode is not limited except by the height of the lamp. This permits the use of an electrode having a long burning life.

1290. Can this type of lamp be operated on alternating current?

No. Since the positive electrode must be copper and the

negative electrode metallic oxide, the current must always pass through the lamp in the same direction. Direct current must therefore be used.

1291. Is the negative rod consumed by the current?

Not entirely; there is some ash, and whatever is not carried

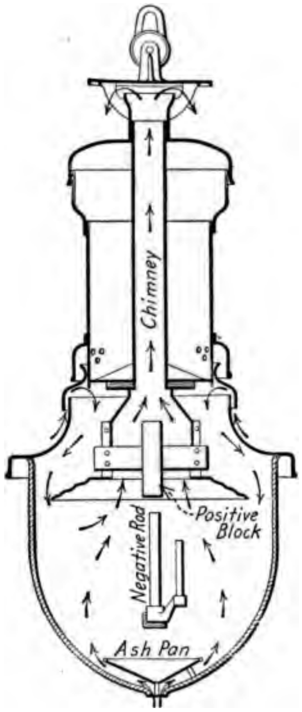

Fig. 434.—Diagram of Metallic Flame Arc Lamp, showing Circulation of Air.

out of the chimney of the lamp by the strong air circulation is deposited in a little pan below the lower electrode. Fig. 434 will illustrate the case.

1292. Does the metallic flame arc lamp operate with constant potential or constant current?

The mechanism described in Answer 1286 operates only

with constant current, but other mechanisms are made for operation on constant-potential circuits.

1293. How is the constant direct-current obtained?

Usually, from what is known as a mercury rectifier, supplied from an alternating-current circuit. The constant-current dynamo was formerly the only available source of such current, but since the development of the mercury rectifier the constant-current machine has become practically obsolete.

MERCURY RECTIFIER

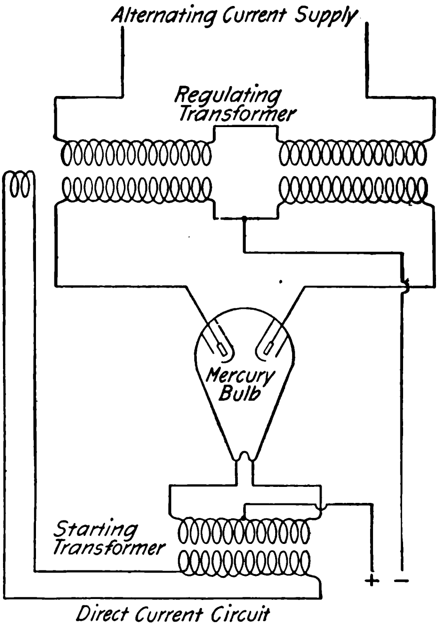

Fig. 435.—Connections for Mercury Rectifier.

1294. What constitutes the mercury rectifier for converting alternating current into a constant direct current?

The mercury rectifier outfit consists of a constant-current regulating transformer, a mercury bulb and a small starting transformer, connected up as shown in Fig. 435 and mounted

on a panel containing the necessary switches, instruments, etc., for operating it.

1295. Explain the connections shown in Fig. 435.

The two secondary coils of the regulating transformer are connected in series, and their free ends are connected to the upper electrodes of the rectifier bulb, which are called "anodes." The two leads from the lower terminals of the rectifier, which are "cathodes," are connected to the secondary terminals of a small starting transformer, the primary of which is supplied from a small auxiliary secondary coil on the regulating transformer. The positive lead to the direct-current circuit is brought out from the middle of the starting transformer secondary winding. The negative direct-current lead is brought out from the connection between the two main secondary coils of the regulating transformer.

1296. Describe the operation of the rectifier outfit.

The bulb is tilted so that the mercury in the two lower electrode pockets bridges the space between them, thereby short-circuiting the starting transformer secondary, which is connected to these lower electrodes, or cathodes. When the bulb is returned to the vertical position, the breaking of the mercury bridge between the cathodes produces a spark which breaks down the resistance at the surface of the cathodes and vaporizes the mercury, from which current passes freely from the mercury to the upper electrodes, or anodes, which are of graphite. The alternating electromotive forces from the regulating transformer, which are alternately impressed upon the two graphite anodes of the rectifier, cannot pass from one of the graphite electrodes to the other, because the current cannot flow from mercury vapor into a solid electrode, although it flows easily from a solid electrode to the mercury vapor. Each impulse, however, passes down from one anode through the vapor to one or both of the mercury cathodes, from which they all emerge in the same direction, resolving into a direct current slightly pulsating in character.

1297. Illustrate and describe the mercury rectifier bulb in detail.

The mercury rectifier bulb is shown separately in Fig. 436. It consists of a pear-shaped glass bulb about 7 inches in diameter at its largest part, provided with four elec-

Fig. 436.—Mercury Rectifier Bulb.

trodes. The two upper electrodes, or anodes, *A* and *A*, are graphite blocks and they are mounted within glass tubes which serve to direct the course of the current from the anodes to a point over the two cathodes, *C* and *C*, which are little pools of mercury. The leading-out wires from the graphite anodes pass through heavy glass plugs which serve to prevent flashing or arcing across. The glass bulb is ex-

hausted of air, like that of an incandescent lamp, to prevent oxidation of the mercury and graphite.

CARE AND MANAGEMENT OF ARC LAMPS

1298. What are the principal features to watch out for, to insure the proper operation of arc lamps?

Assuming that the lamps are substantially made, their proper operation depends chiefly upon their being properly trimmed and correctly adjusted for the voltage at which they are designed to work.

1299. In trimming an arc lamp, what are the important points to be observed?

The use of proper carbons; removal of dirt from the clutch rod before pushing the rod up; placing the carbons so that they are vertically in line with each other and have enough vertical play to allow the lamp to pick up its arc; care to see that the carbon rods are firmly screwed into their holders; inner globes thoroughly cleaned, and if nicked or cracked so as to allow leakage of air, to be replaced by new globes; proper adjustment of the moving parts.

1300. How should the carbons for enclosed arc lamps be selected and replaced?

The carbons used should be of the best quality so that the quantity of deposited matter due to combustion will be as small as possible; they should be free from blisters or roughness, hard spots and curves. A good guide as to the quality of the carbon is the appearance of the burned ends. Good carbons after being used present a dull surface, whereas the ends of hard carbons present a glossy pitted surface.

The trimming of enclosed arc lamps outdoors is facilitated by the trimmer taking with him a clear inner globe fitted with a lower carbon, to replace the old one in each lamp. It is necessary that the carbons be of the proper length. The upper carbons can be purchased of the desired length, but as the lower ones are often made up of the

part left over from the upper carbon they should be cut to the proper length before being used for this purpose.

The proper operation of an enclosed arc lamp depends largely upon the free passage of the upper carbon through the cap of the inner globe. A ½-inch carbon should not be smaller than 0.5 inch nor larger than 0.52 inch; if smaller than 0.5 inch, too much air will be admitted and the arc will flame.

1301. What is the method of adjusting an arc lamp for the proper voltage?

Before an arc lamp is installed, it should be adjusted for its proper arc voltage, which is usually 70 to 75 volts measured across the enclosed arc. The lamp should be burned about ten minutes before this measurement is taken so as to allow the carbons to assume their normal operating condition. Directions for adjusting the different makes of arc lamps vary considerably, so that no specific rules can be given to fit all cases. Directions, however, can be obtained from the manufacturers and they should be closely followed to secure satisfactory results. When adjustments are made without the use of a voltmeter, it is well to bear in mind that if the arc hisses it is too short, and if it flames badly it is too long. By watching the fluctuations of a voltmeter across the arc, as the carbons burn, a good idea may be formed of the smoothness with which the mechanism feeds.

1302. In case a lamp does not feed properly, where is the trouble usually found?

In the dash-pot or in the clutch, if the feed magnet is not burned out.

1303. How may trouble in the dash-pot be remedied?

By wiping it clean with a dry cloth. If this does not clear the trouble, remove the dash-pot and clean with gasoline the little check valve which has probably become stuck. Oil should never be used on it. If the valve is all right, the piston

has probably worn loose, in which case a new one should be used.

Where arc lamps are used only occasionally, but must be kept ready for immediate service, the formation of scale inside the cylinder of the dash-pot may be prevented by lighting the lamp for a minute or two every day. This daily action

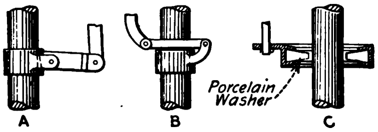

Fig. 437.—Arc Lamp Clutches.

of the piston will scrape off the scale before it hardens sufficiently to interfere with the performance of the dash-pot.

1304. How may trouble in the clutch be remedied?

In two-part metal clutches, such as shown at *A* and *B*, Fig. 437, dirt is liable to work in between the parts, which will then require cleaning. If, through the breaking of the upper carbon lead, the clutch is forced to carry the lamp current, it is liable to burn and bind the pivot pins. In all two-part metal clutches it is necessary to keep these pins loose to insure free operation. The porcelain washer clutch *C*, Fig. 437, is not subject to pin trouble, but may break if there is "jumping" of the carbons, in which case a new porcelain washer must be substituted.

CONNECTION OF ARC LAMPS IN CIRCUIT

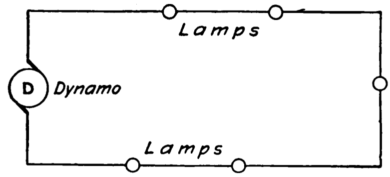

Fig. 438.—Arc Lamps in Series.

1305. How are arc lamps usually connected for street lighting?

In series, as indicated in Fig. 438.

1306. What are the current and the voltage conditions in a series circuit?

The current through all the lamps is the same, assuming there is no leakage, and this current must be kept constant to obtain a steady illumination. If each lamp requires 75 volts, and there are fifty lamps in circuit, the generator must develop

$$50 \times 75 = 3750 \text{ volts}$$

plus the drop in the line.

In case any of the lamps are cut out by short-circuiting them, this being the only way in which lamps on a series system can be cut out without opening the circuit, it is evident that if the voltage remains constant the current will

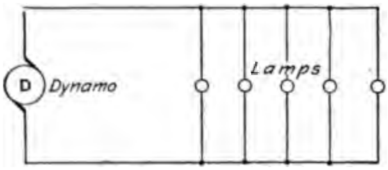

Fig. 439.—Arc Lamps in Parallel.

increase and perhaps burn out the lamps remaining in circuit. To prevent an increase of current under these conditions, an automatic regulator is used in connection with the generator.

1307. How many lamps can be operated in a series circuit?

About 100 lamps is the maximum that is considered practicable on a single circuit. This requires an electromotive force of approximately 7500 volts.

1308. How are arc lamps usually connected for interior lighting?

In parallel across a constant-potential circuit, as shown in Fig. 439.

1309. What are the voltage conditions in the parallel circuit?

As the usual interior constant-potential circuit is operated at about 110 volts and the voltage across the enclosed arc is approximately 75, there remains about 35 volts to be taken up by the resistance in the direct-current lamp, or by the reactance in an alternating-current lamp. In an open arc lamp, however, the voltage across the arc is only about 45 to 50, so that from 60 to 65 volts is wasted in dead resistance.

1310. Is the greater loss of voltage in the open arc lamp responsible for this lamp being superseded by the enclosed arc lamp for parallel connection?

Not entirely, because it is possible to operate two open arc lamps in series across a 110-volt circuit, leaving only about 20 volts to be lost. The enclosed arc lamp won out chiefly by reason of the slower combustion of the carbons and consequent saving in operating and maintenance cost, the softer light it gives, the better distribution of this light by means of the inner globe, the impossibility of heated carbon particles flying out and setting fire to inflammable material and its quietness in operation.

1311. How are indoor lamps suspended and wired in circuit?

Two approved methods of arc lamp suspension and wiring are shown in Fig. 440; at the left the method for exposed wiring, and at the right the method for concealed wiring. In both cases it is seen the lamp does not depend upon the feed wires for support, this being effected by a central suspension wire or conduit. In addition to the insulator at the top of the lamp, there should be one in the suspension hook or wire to serve as further protection. Each lamp on a constant-potential circuit should be protected by an enclosed fuse, which may be of the cartridge type, mounted above the lamp,

as shown at the left of Fig. 440, or it may be of any other approved form connected in the lamp circuit and mounted at a distance from the lamp. This latter method is the more convenient one when concealed wiring is used and accounts

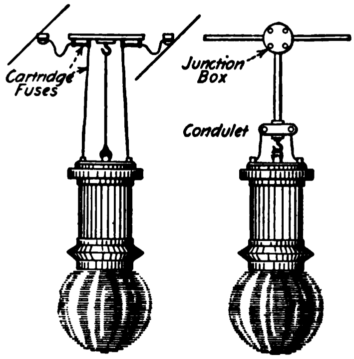

Fig. 440.—Method of Suspension for Arc Lamps.

for the absence of protective devices in the sketch at the right of Fig. 440, the conduit and junction box there shown being merely for convenience in wiring the lamp into circuit.

SUBSTATIONS

1312. What is a substation?

An electrical station in which current is received from one or more large generating stations and in turn supplies a number of feeders which distribute it over the locality where it is used.

1313. Under what conditions is a substation mostly used?

In electric railway work, where the traffic is heavy and the system of distribution widespread; although in some cases it is used for power and lighting systems.

1314. What advantage is gained by the use of a substation in electric railway work?

One large power station can be used for the entire system. This enables the electrical energy to be more economically obtained than when more generating stations are employed.

1315. Is the current handled in a railway substation direct or alternating?

The currents received at the substation from the generating plant are alternating and of high voltage. These are stepped down by transformers, and by means of rotary converters are changed into direct current, usually at 550 volts, and supplied to the feeders.

1316. Why are transformers required in the substation?

To lower the voltage of the alternating current supplied from the generating station, so that it is adapted to the rotary converters. This is necessary on account of the fixed ratio which the voltage on the alternating-current side of a rotary converter bears to that on the direct-current side. In a three-phase converter this ratio, according to Answer 1140, is 61

per cent.; hence alternating current at approximately 335 volts would be necessary to supply direct current at 550 volts.

1317. Are motor-generators used in substation work?

Motor-generators are seldom used on account of their higher cost as compared with the rotary converters and transformers they would replace.

1318. Are all substations alike with respect to the method of receiving and distributing the power?

No. A substation may receive current from the generating station and without any transformations whatever distribute it through switches to other circuits. Another kind of substation may receive high-voltage alternating current from the generating station and, through transformers, reduce its voltage for distribution. A third, as previously described, may receive high-voltage alternating current and distribute low-voltage direct current. Still other substations, common in electric railway service, carry either storage batteries alone or storage batteries and boosters.

1319. When are storage-battery substations advantageous for railway work?

When maintaining a very uniform line voltage and compensating for an extra length of feed wire; relieving the power house of fluctuations of load, keeping the cars moving when the power supply is temporarily interrupted, or in supplying power for the operation of a few cars or lights when the power house is shut down.

1320. When are boosters used in connection with a storage battery in a substation?

When current is to be transmitted over a considerable distance to a storage-battery substation for the purposes mentioned in Answer 1319 and the battery must furnish current at the same voltage as developed in the generating plant. The booster makes up for the drop of potential in the line between the generating station and the substation, while the battery is being charged. Also, in railway work, where the

load fluctuates within wide limits, a booster is used in connection with the battery. In this case a "differential booster" is used having both series and shunt field windings. Thus the electromotive force varies automatically with the load and adds to or subtracts from the battery voltage as required.

1321. What factors govern the location of a substation?

Practically the same factors that govern the location of a central station, namely: nearness to the center of distribution

Fig. 441.—Typical Form of Substation Building for Rotary Converter Equipment.

so that the drop of potential in the different circuits may be a minimum; also the cost of real estate.

1322. What kind of a building is best for a substation?

A detached building, built preferably of brick or other fireproof material, as in Fig. 441, which shows a rotary converter substation.

1323. What provision should be made for light?

The substation should be constructed so that plenty of light will enter it, but in a storage battery room the sun should not shine on any part of the battery. A substation used exclusively for a storage battery is sometimes built as

in Fig. 442, without windows, dependence being placed entirely upon incandescent electric lamps for light.

1324. What provision should be made for ventilation?

The ventilation of the storage battery room must be particularly good to prevent the accumulation of fumes; otherwise, it will be almost impossible to enter the room while the battery is being charged, and the hydrogen gas given off while

Fig. 442.—Storage Battery Substation.

charging, being inflammable, is likely to cause a serious accident if ignited.

The room in which the machines are installed should also have good ventilation, because the heat developed in them, even during their normal operations, will considerably increase the temperature. Good ventilation is likewise important where oil-cooled transformers are used, so that the temperature may not become unduly high in the summer-time.

1325. Is there any reason why the machines and battery should not be located in the same room?

The battery should be placed in a room by itself so that the sulphuric-acid fumes given off from the cells will not corrode the metal of the machines.

1326. What provision should be made for the drainage of a substation?

Where air-blast transformers are used, the walls of the air-blast chamber should be waterproofed and the substation should be built at such an elevation that water will not stand on the floor of the air-blast chamber. If this latter precaution is not taken, the transformers may be damaged by the warm air from the blower picking up moisture and depositing it in the transformers which are not in service.

When oil-cooled transformers are used, it is well to install a pit of sufficient capacity to drain the oil from several transformers, and to provide drainage piping of ample size from the oil drain-cocks on the transformers to the pit, so that the oil can be drawn off quickly in case of fire or other emergency.

In the battery room the floor, which must never be of wood, but of vitrified brick or some other material that is not affected by sulphuric acid, should slope downward toward a drain so that when flooded in washing it will dry off rapidly.

Where cables come into the station underground, the entering conduits should be sealed and suitable drainage provided so that water cannot leak into the cellar through these openings.

1327. Give an idea of the general arrangement of substation apparatus.

The arrangement of substation apparatus is largely dependent upon the nature of the switching apparatus. When the cables enter the station overhead, the hand-operated switches are invariably of the top-connected type and the high-voltage bus-bars are mounted above them. A typical arrangement of this kind is shown in elevation and plan in Fig. 443, which is an 11,000-volt installation where oil-insulated self-cooling transformers are used. The high-tension panels are located in front of their respective oil switches and on the operating side of the transformers.

1328. What arrangement of substation apparatus is cus-

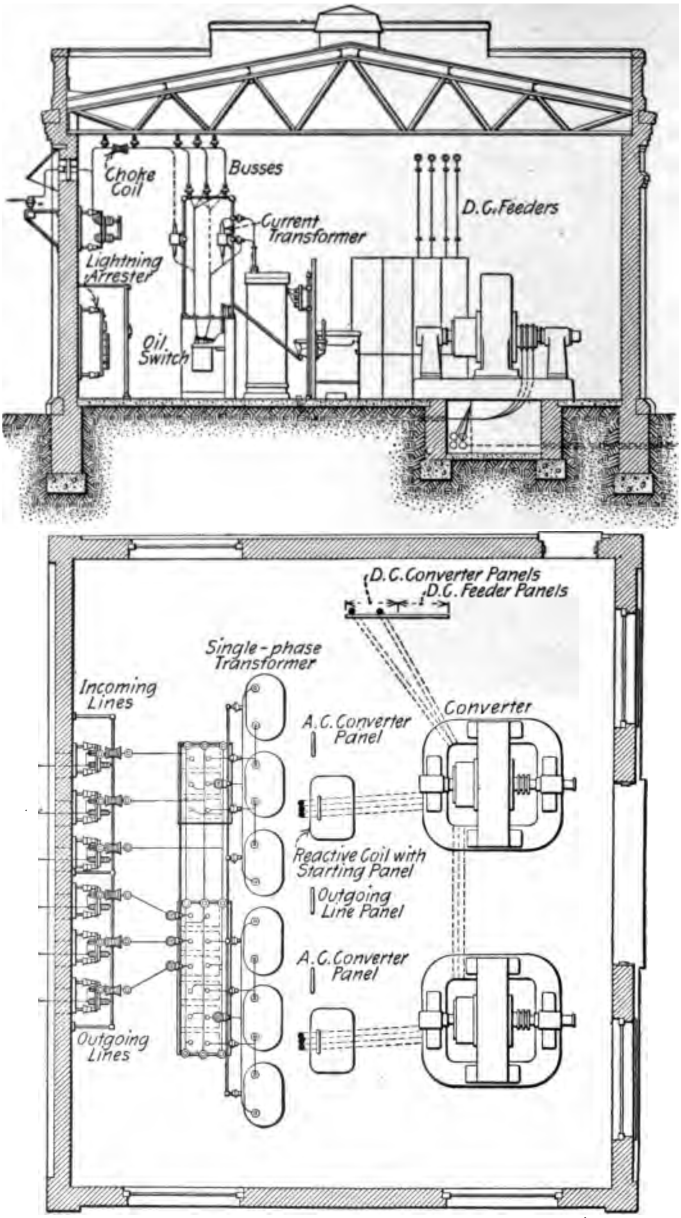

Fig. 443.—Typical Substation Arrangement with Feeders entering Overhead,—Elevation and Plan.

tomary in case the incoming cables are underground and the switches are motor-operated?

Fig. 444 shows a section through a substation to meet these conditions. The switches are bottom-connected and the bus-bars and all high-tension connections are placed below the floor in a suitable compartment. The connections from the high-

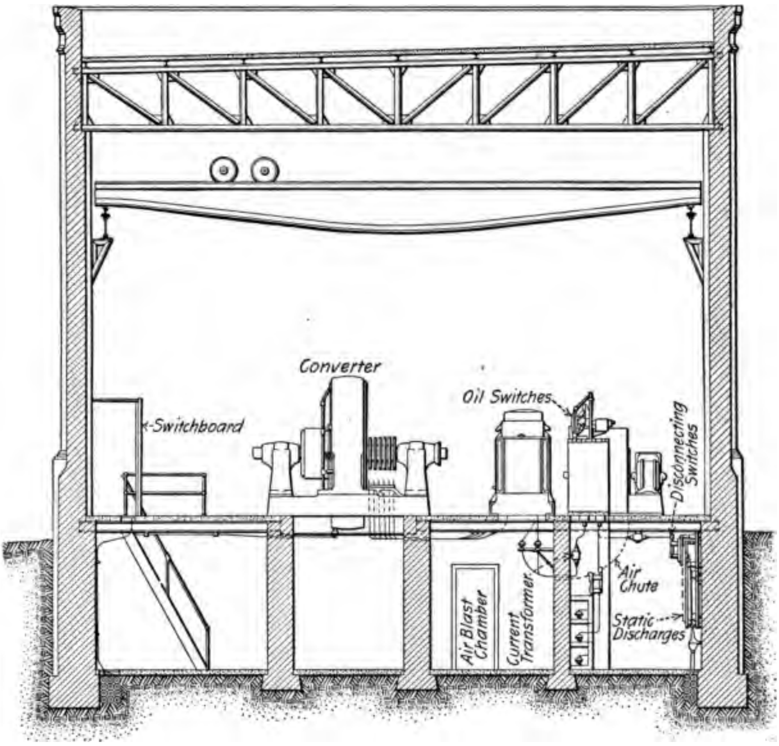

Fig. 444.—Section through Substation with Underground Feeder Cables.

tension switches to the transformers pass through the partition wall between the high-tension compartment in the basement and the air-blast chamber. The transformers in this case are bottom-connected; that is, both the high-tension and the low-tension leads are brought through their bases. All

the main panels, both alternating-current and direct-current, are in one switchboard.

1329. What is the usual arrangement for the switchboard panels?

In general, the direct-current switchboard panels are arranged in a group by themselves, the converter panels to the left and the feeder panels to the right, with room for extension at either end. Usually no attempt is made to group the

Fig. 445.—Arrangement of Storage Battery where Floor Space is Limited.

oil switches, either hand-operated or electrically operated, behind the main switchboard, the oil switches being invariably located, in the more recent types of construction, immediately adjacent to their banks of transformers or line entrances, or exits, as the case may be. For all stations using hand-operated switches, this makes it advisable to locate the alternating-current line and converter panels in corresponding positions. With electrically operated switches, there is

no definite relation between the location of the panel and its switches. No incoming line panels are used unless the lines are in duplicate, a single incoming line being wired to the substation bus-bars without oil switches, but with disconnecting switches.

1330. Upon what considerations does the arrangement of a storage-battery substation depend?

Principally upon the amount of available floor space and the accessibility of the cells for inspection and handling.

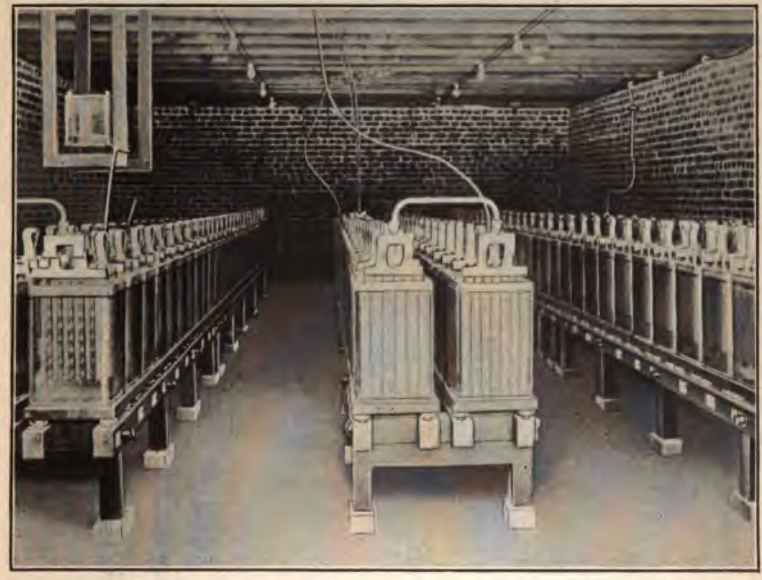

Fig. 446.—Arrangement of Battery where Floor Space is Not Limited.

1331. When the floor space is limited, what is the best arrangement of the cells?

In tiers, one above the other, as shown in Fig. 445.

1332. Are the cells in Fig. 445 convenient for inspection and handling?

Inspection of the cells is not difficult in this installation

because ample room has been left between the two tiers and between the ceiling and the upper tier. The handling of the cells, however, is not convenient; without a traveling crane it would be almost impossible to move any of these cells with ease and safety.

1333. Where the floor space is not limited, what is the best arrangement of the cells?

In rows on supports resting upon the floor, as in Fig. 446.

Fig. 447.—Portable Railway Substation.

1334. Is there any objection to placing the cells directly upon the floor?

It is not advisable to do this because moisture would accumulate under the cells, and this, together with the battery solution, would form a conducting path from one cell to another and cause leakage of current. Hence, it is customary to use insulating supports under the cells.

1335. What is gained by having the cells rest upon a

board over the insulators, as in Fig. 446, rather than directly upon the insulators?

The board prevents any unequal distribution of the weight of the battery from causing the insulators to be strained or broken.

1336. Is there any objection, where the space is limited, to placing adjacent cells so close to each other that their cases touch?

Adjacent cells must be kept far enough apart so that there

Fig. 448.—Rotary Converter in Portable Substation shown in Fig. 447.

will be no possibility of coming in contact, else the battery solution is likely to creep across, causing leakage of current.

1337. Are provisions ever made in a railroad substation, other than by the overload capacity of the apparatus installed, for taking care of unusually heavy loads at infrequent intervals?

A portable substation is sometimes used for this purpose.

1338. What is a portable substation?

A car such as shown in Fig. 447 arranged for carrying a rotary converter, Fig. 448, transformers, and a switchboard,

Fig. 449. Such a station for increasing the direct-current supply may be quickly moved to any part of the line, as to

Fig. 449.—Switchboard in the Portable Substation in Fig. 447.

fair grounds, amusement parks or summer resorts which are to be served only a few days or weeks.

MANAGEMENT OF ELECTRICAL STATIONS

1339. **Does not the successful operation of an electrical station depend largely upon having system in the work to be done?**

Yes; because with a proper system each attendant has his special duties to perform, someone is responsible for whatever is to be done and the chance of overlooking matters is reduced to a minimum.

1340. **What provision should be made to safeguard attendants?**

Belts and moving parts of machinery should be enclosed with railings or guards, and the dark pits and passages, such as back of the switchboard, must be well lighted, as shown in Fig. 450. Exposed bars or conductors running through the station for carrying current should be painted to distinguish them from ordinary structural work. Yellow is suggested for potentials up to 250 volts; blue from 250 volts to 1000 volts; and red for potentials over 1000 volts. "Stumbling blocks" should be removed or made as few as possible. There should be no doors, cupboards, storage or obstruction of any kind behind the switchboard, and this space should not be used as a thoroughfare. There should be at least 4 feet actual clearance between the back of the switchboard and the wall, and the ends of this space should be guarded by railings or screens which will permit of a clear view back of the board. Switchboards on which high-voltage currents are handled should have an insulated space in the floor or an insulated platform in front of the board, as shown in Fig. 450. The same precaution should be taken with the generators, especially if of high voltage and the frames are not grounded.

1341. Should the generator frames be grounded?

Generators operating at a potential over 550 volts should have their base frames permanently grounded.

1342. What advantage results from grounding a generator frame?

Grounding a frame removes the possibility of dangerous shocks when coming in contact with it. The insulation of

Fig. 450.—Electrical Station Interior, showing Properly Lighted Passages back of Switchboard and Transformers.

the entire system then depends upon the insulation of the generator conductors, from the frame; if this breaks down, the system is grounded and the condition is indicated at once by the switchboard instruments.

1343. Is there any argument against grounding a generator frame?

Yes; the insulation resistance of the entire installation is reduced and there is an increased danger of shock from the line wires. These objections, however, can be overcome by employing a thorough system of insulation,—a precaution which should obtain in any case, and which in consequence lessens the force of the argument against the practice.

1344. How may a generator frame be properly grounded?

By securely fastening one end of a wire to the frame and the other to a main water pipe inside the building. With a direct-connected generator an excellent ground may be had through the engine coupling and piping.

1345. Is there need of any precautionary construction around high-potential generators?

High-potential generators with their frames grounded should be surrounded by a wooden platform raised above the floor on porcelain or glass insulators so that those working about the machines may be protected from shock when adjusting the brushes, etc.

1346. Should not generators operating at 550 volts or less be grounded?

No; they should be insulated from the ground by wooden base frames or a wooden floor kept perfectly dry and clean.

1347. How should generators be protected when not in use?

Waterproof covers should be placed over them. Otherwise water may get into the working parts and cause an armature or field coil to burn out when the machine is started.

1348. What provision should be made in the station wiring and apparatus to afford safety from fire?

The station wiring and apparatus should conform to the rules and requirements of the National Board of Fire Under-

writers. These are embodied in the "National Electric Code," a booklet which may be obtained free upon request from the electrical department of the National Board of Fire Underwriters, 135 William Street, New York City.

1349. What kind of fire-extinguishing apparatus should be placed in the station?

Every station should be supplied with a fire pump and an adequate line of pipe and hose. The pump should be run at least once a week and kept in good working order. Care should be taken in locating the sprays and pipes so that water will not come in contact with the generators or the conductors. Also fire buckets filled with water should be placed in convenient places. Furthermore, it is important to have at hand a number of buckets filled with dry sand, which may be used in extinguishing fire between electrical conductors where water would do more harm than good. The buckets should be kept covered to prevent the sand from being blown around in the station.

1350. What should be done to insure cleanliness in the station?

The machines must be kept free from grease and dirt. Greasy rags and waste should not be thrown carelessly around, but should be placed in cans provided for the purpose. Filing or repairing of any kind that produces dust or small particles of metal should, if possible, be performed elsewhere than in the generator room. Another aid to cleanliness and order is to keep all supplies under lock and key in a store-room.

1351. How should the stock in the store-room be handled?

If the station is large, there should be a person whose only duty consists in keeping charge of the supplies; and accurate accounts should be made by him of all receipts and disbursements. Applications for material should be made on regular printed forms which may be placed on file and used in keep-

ing the stock books and accounts. In smaller stations, the store-room keeper may perform other duties as well.

1352. What is the best method of issuing orders to the station attendants?

Having them plainly written and fastened by means of thumb tacks upon a bulletin board in a conspicuous part of the station. All operating orders, such as the dynamo schedule, circuit schedule and orders for changes, should be handled in this manner. Each dynamo and each circuit should have its number, and the orders should make it unmistakably plain as to when each dynamo shall start and stop; also during what time and from which machine, each circuit shall be operated. There should always be room left on the board for a notice to be posted when a high-voltage line is being worked on, and when a man is in a flywheel pit or in any other position where he is liable to be injured by the starting of some particular machine.

1353. Why are reports of value in the operation of a plant?

Without accurate reports an engineer cannot keep a check on what is being done.

1354. What is the best way of collecting material for the reports?

By means of recording instruments and keeping all the paper dials or cards obtained from them on file. Most of the necessary calculations may be made from these records. When the station is not provided with recording instruments, the different meters in service should be read at least every half hour and the readings entered on regular report blanks. In large stations there should be separate blanks for the different departments, but in a small station one blank may be used for all.

1355. Give an example of a common form of power house report.

Fig. 451 represents a power house report on four machines for one day, from midnight to midnight, the generators being driven by two water-wheels. Two of the generators are 550-volt direct-current machines, the third is a 2000-volt alternator having a capacity of 75 amperes, and the fourth an arc-light generator carrying a load of forty-five 2000 candle-power open arc lamps. There are but three circuits, the two direct-current generators being run in multiple when the load exceeds 100 amperes.

1356. What information regarding the operation during the 24 hours may be obtained from the report, Fig. 451?

In the vertical columns are recorded the readings on the instruments of each machine, at the end of every half hour. At the end of a day's run, the columns are added and averaged; the values are then recorded in the upper right-hand corner, as shown. The voltmeter for the alternator is connected across the secondary wires of a transformer that reduces the pressure to 100 volts when the current is generated at 2000 volts; in other words, it transforms the voltage in a ratio of 20 to 1. In making out the report, the voltage across the secondary terminals of the transformer is recorded. The arc-light voltage across the terminals at the switchboard is recorded and indicates, approximately, the number of lamps burning when the readings are being taken. This voltage is usually entered in round figures, that is, to the nearest multiple of 50—the voltage per lamp. The average voltage is treated in the same manner.

1357. How are the calculations relating to the individual generators arrived at?

At the end of the day the average current from each generator is multiplied by its average voltage, giving the average watts developed by the machine. This multiplied by the number of hours it has been in operation and divided by 1000 gives the output of the dynamo for the day, in kilowatt-hours. By adding together the outputs of the machines, the total work done by the plant will be found, which, in this

THE POWERVILLE ELECTRIC CO.

POWER HOUSE REPORT

TUESDAY, JAN. 16, 1911

TIME.	DYNAMO NOS. 1 A	1 V	2 A	2 V	3 A	3 V	4 A	4 V
12.30	40	500			20	103	10.2	1250
1.00	30	500			18	103	10.2	1100
1.30	30	500			15	102	10.5	1000
2.00	20	500			12	102	10.5	1000
2.30	40	500			10	101	10.5	1000
3.00	20	500			14	102	10.4	1050
3.30	15	500			28	104	10.3	1150
4.00	50	510			32	104	10.2	1500
4.30	60	525			37	105	10.2	1850
5.00	65	540			37	105	10.2	1850
5.30	80	540			25	103	10.1	1950
6.00	110	525			23	103	10.5	1000
6.30	80	530	45	530	20	103	10.5	1000
7.00	70	530	70	530	16	102		
7.30	100	550	100	550	14	102		
8.00	100	550	90	550	9	101		
8.30	90	550	90	550	10	101		
9.00	95	550	85	550	10	101		
9.30	80	550	75	550	15	102		
10.00	60	540	65	540	14	102		
10.30	65	540	65	540	16	102		
11.00	80	545	65	545	16	102		
11.30	80	545	70	545	15	102		
12.00	90	550	85	550				
12.30	90	550	85	550				
1.00	90	550	80	550	12	102		
1.30	85	550	85	550	14	102		
2.00	80	550	75	550	14	102		
2.30	75	550	75	550	14	102		
3.00	75	540	60	540	15	102		
3.30	70	540	60	540	16	102		
4.00	80	550	75	550	20	103		
4.30	80	555	80	555	28	104		
5.00	100	555	90	555	39	105	10.5	1050
5.30	105	560	105	560	58	108	10.3	1200
6.00	100	560	110	560	70	109	10.1	1950
6.30	90	550	110	550	75	110	9.8	2250
7.00	90	550	95	550	78	110	9.8	2250
7.30	80	550	90	550	76	110	9.8	2250
8.00	80	540	85	540	75	110	9.8	2250
8.30	60	530	80	530	73	110	10.2	2200
9.00	50	540	70	540	73	110	10.2	2200
9.30	40	530	65	530	65	109	10.2	1850
10.00	40	530	50	530	55	107	10.2	1700
10.30			85	555	40	105	10.2	1400
11.00			45	535	38	105	10.2	1400
11.30			45	525	29	104	10.2	1350
12.00			40	500	25	103	10.2	1250

Dynamo Nos.	Started	Stopped.	Hrs. Run.	Averg. Amps.	Averg. Volts.	Kilowt. Hours.
1	12.00 p.m.	10.00 p.m.	22.0	70.7	536.4	834
2	6.30 a.m.	12.00 p.m.	17.5	76.3	543.8	726
3	12.00 p.m.	11.30 a.m.				
	1.00 p.m.	12.00 p.m.	22.5	31.0	104.2	73
4	12.00 p.m.	6.30 a.m.				
	5.00 p.m.	12.00 p.m.	13.5	10.2	1550	213
Wheel No. 1	12.00 p.m.	11.00 p.m.	23.0			
" 2	4.00 a.m.	12.00 p.m.	20.0			

Average No. Arc Lamps........................ 31
Average No. Incandescent Lamps.............. 1,240
Total No. Incandescent Lamp-hours........... 27,900
" " Kilowatt-hours........................ 1,846
Head of Water, 6 a.m., 27 ft. 4 in.; 6 p.m., 27 ft. 6 in.

Supplies Received.

31 gal. cylinder oil.
31 " Renown engine oil.
4 doz. dynamo towels.
6 " 10-in. files.

Supplies Used.

1 gal. cylinder oil.
2 " Renown engine oil.
1 " O.K. dynamo oil.
2 cans potash.
1 10-in. file.

REMARKS.

Short circuit on dynamo No. 1, from 6.10 a.m. to 6.20 a.m.

Continued heavy ground on dynamo No. 3 Occasional poor contact in arc circuit.

Dynamo No. 2 running exceptionally warm.

Signed,

JOHN BROWN.

Fig. 451.—Form of Power House Report.

case, is 1846 kilowatt-hours. This may be changed to horse-power by multiplying by 1000 and dividing by 746; or what amounts to the same thing, by multiplying the number of kilowatt-hours by 1.34.

1358. Why is it necessary to record the average number of arc and incandescent lamps that are burning during the run?

Because the revenue of a lighting company is normally figured on this basis.

1359. How is the average number of arc lamps calculated for the report?

The number of arc lamps is directly proportional to the voltage of the arc dynamos; therefore, dividing the average pressure, 1550, by 50, which may be taken as the voltage of each lamp, the result will be approximately the average number of lamps burning during the run of 13½ hours, which in this case is 31.

1360. How is the average number of incandescent lamps calculated for the report?

This may be calculated from the current of the alternator. The 16-candle-power lamp is taken as the standard, and it is customary to allow 50 watts for such a lamp. If the voltage is 100, each lamp will consume ½ ampere, and, since the ratio of the transformer is 20:1, 20 amperes in the secondary winding will result from a current of 1 ampere in the primary; consequently there will be 40 lamps ($20 \div \frac{1}{2}$) burning in the secondary circuit for each ampere of current generated by the alternator. The machine was delivering on an average 31 amperes, making the average number of incandescent lamps

$$31 \times 40 = 1240.$$

Multiplying this number by 22½ hours during which the alternator was running, shows the number of lamp-hours to be 27,900.

1361. Is it not sometimes more desirable to know the

total kilowatt-hours supplied to the different parts of a system, than to know the average number of lamps burning?

It may be; in which case this part of the report should be changed to suit conditions.

1362. What information belongs under the heading "Remarks"?

Notes regarding the general condition of the plant and of the individual machines, especially when anything out of the regular order occurs. It is especially important to give an accurate and minute description of all accidents, together with their causes. Carefulness in this matter often enables the engineer to shake off responsibilities that are liable to be heaped upon him by other parties.

1363. What conditions besides those previously mentioned will affect the general make-up of the report?

When there are many different circuits, the time when they are opened and when they are closed should be noted, together with the conditions of the circuits. When this is done, it is best also to note the state of the weather, since that greatly affects the condition of the lines.

The report shown is for a water-power plant. When steam is used, a report of the boiler room, etc., is usually included. An extra column is also provided for a record of the steam pressure, and space must be left to show when the fires are started, when the boilers are cleaned, the amount of fuel received and consumed, and further data necessary to make a complete report. Here, again, a variation may take place. A separate report may be kept of the steam plant, which may be done by an engineer who has nothing whatever to do with the dynamos, etc. This method is generally adopted in large plants, but in small plants it is not necessary and will only cause extra labor.

1364. How often should power-house reports be turned in to the office?

In most companies it is required that a report be sent to

the office each day; but sometimes only the general information regarding load and accidents is wanted, in which case it is advisable always to make out a full report as explained, and then make a synopsis of this for the office.

1365. What is the best method of furnishing the office

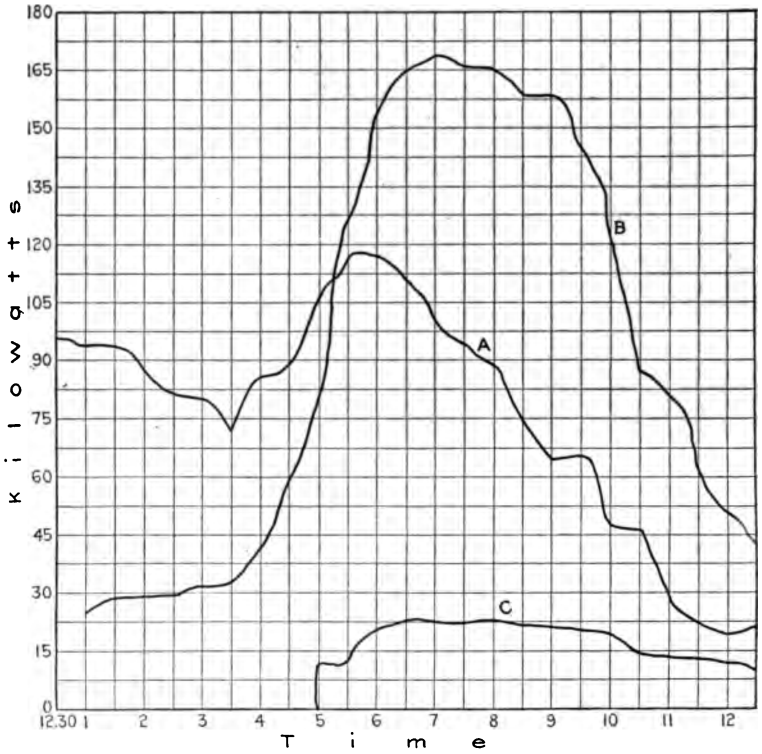

Fig. 452.—Typical Load Curves.

with information regarding the loads carried by the different machines?

Plot the readings on a sheet of co-ordinate paper, as shown in Fig. 452.

1366. Explain how the graphical report in Fig. 452 fur-

nishes information regarding the loads on the generators recorded in Fig. 451.

Curve *A* represents the output of dynamos Nos. 1 and 2, curve *B* the output of the alternator and curve *C* the output of the arc-lamp dynamo. The height of the curve *B*, for instance, at 8 P.M. shows the output of the alternator at that moment to be 165 kilowatts. When desired, a curve may be similarly drawn showing the combined output of all the generators.

1367. Does the management of a substation differ from that of a central station?

Only in minor details. Rotary converters with synchronous motors, as has previously been explained, are started somewhat differently from ordinary generators and they are not handled in exactly the same way when they are brought to rest. They are, however, taken care of and repaired in the same manner as generators. The principal thing to observe is that these machines must not be thrown onto the line unless they are in step with the apparatus supplying the current. They must also be protected with reliable safety devices that will open the circuit if they should be pulled out of step.

1368. Is electrical station work a dangerous occupation on account of the possibility of receiving shocks?

It is dangerous work for careless men, especially where the current is generated at high voltage. Because a wire or busbar carrying current appears the same as it would were it not carrying current, the workers must rely entirely upon their knowledge of the circuit conditions. Ordinarily, it is not difficult to trace out a circuit before working upon it, to determine whether it is connected to a live source and thereby avoid danger.

1369. Is the human body a good conductor of electricity?

It is a poor conductor; under the most favorable conditions it offers a resistance of about 2500 ohms. This is the resistance of 300 miles of ordinary telegraph wire. The chief

resistance is that of the skin which, when dry, is about 100,000 ohms.

1370. What voltage is considered fatal?

Less than one ampere (about 0.8 ampere) of current flowing through the body will produce death, although less than this is often fatal. With the resistance of the body taken at 2500 ohms, the voltage corresponding to the fatal current is, according to Ohm's law,

$$0.8 \times 2500 = 2000 \text{ volts.}$$

However, people are frequently killed by much less voltage than this.

1371. What voltage is considered dangerous?

As before stated, the skin of the body offers a high resistance, and this is particularly true of the hardened skin about the hands, where accidental contact is usually made. Because of this, shocks from pressures below 200 volts need be avoided only on account of the unpleasant sensations. With pressures about 200 volts, care should be exercised to guard against accidents and particularly so in the case of alternating current.

1372. Have not persons lived after receiving 100,000 volts or more?

Yes; voltages as high as 100,000, which are confined to alternating currents of high frequency, often produce what is known as a "skin effect," that is, the currents do not penetrate the body to any extent but pass over its surface. Therefore, very high voltages are less frequently fatal than moderately high ones.

1373. What is the best safeguard against dangerous or fatal shocks?

The best safeguard is to make all connections before the current is passed through the circuit. This may be accomplished by introducing a switch in series with each of the main supply wires and the rest of the circuit; and leaving

these main switches open until all the other connections are made.

1374. **If the safeguard just mentioned is not practicable, what are the next best precautions?**

When working on live circuits, never place the body so that it can come in series with the circuit, or in contact with a part of the circuit at a potential different from that of the wire being held. To prevent this, stand on a dry piece of wood or other insulator and work with one hand as much as possible, keeping the other on some insulating support or in the pocket.

In the case of alternating currents having pressures above 1000 volts, too much care cannot be taken, as the leakage is often sufficient to cause a dangerous shock, even though direct contact is not made with the charged parts. Insulated wire often fails to give protection, and it should not be touched unless one stands on a well-insulated support and wears rubber gloves, rubber shoes, or both. It is always well to use tools having insulated handles.

1375. **What are the chances of successfully reviving victims of electrical shocks?**

Prompt and continued efforts along the proper lines have proved successful. In order that the task may not be undertaken in a half-hearted manner, it is well to bear in mind that accidental shocks seldom result in death unless the victim is left unaided for too long a time, or efforts at reviving are stopped too soon. In the majority of instances, owing to short and imperfect contact with the conductors, the shock merely temporarily paralyzes the nerves controlling the muscles of respiration.

1376. **What should first be done to revive a victim of electrical shock?**

The body must be removed at once from the circuit by breaking contact with the conductors. This may be done without danger of shock to the rescuer by using a dry stick of wood with which to roll the body over to one side, or to brush

away the live wire. In the absence of a stick, any dry piece of clothing may be used in seizing the victim. If the body is in contact with the earth, the coat tails of the victim, or any part of his clothing, if dry, may safely be seized to draw the body away from the conductors. Care should be taken, however, not to touch the soles or heels of his shoes while he remains in contact with the live wire, as the nails are conductors.

1377. If the body must be touched in order to move it away from contact with the circuit, what precautions should be observed?

Cover the hands with rubber gloves, a mackintosh, rubber sheeting or dry cloth and stand on a dry board or on some other dry insulating surface. It is safer to use only one hand. In case the victim is conducting the current to ground, and is convulsively clutching the live conductor, it may be easier to break the circuit through his body by lifting him than by leaving him on the ground and trying to break his grasp. A still easier and a much safer and better way, of course, is to open the switch if it is nearby.

1378. If necessary to cut a live wire in order to break the circuit, how should it be done?

Use an ax or a hatchet with a dry wooden handle, or thoroughly insulated pliers.

1379. After the body has been removed from the circuit, what course should be followed?

Send for the nearest doctor; this should be done without a moment's delay. Then quickly feel in the victim's mouth and remove any foreign matter such as tobacco, false teeth, etc. Having done this, efforts should be made to force the victim to breathe. Do not stop to loosen the patient's clothing; every moment of delay is serious.

1380. What method should be employed to force the victim to breathe?

The Schaefer or "prone pressure" method has been rec-

ommended by a joint committee of the American Medical Association, the American Institute of Electrical Engineers and the National Electric Light Association, and this method should be employed.

1381. Explain in detail what should be done in accordance with the method referred to in Answer 1380.

Lay the subject upon his abdomen as in Fig. 453, with arms

Fig. 453.—Treatment for Electrical Shock: Inspiration—Pressure Off.

extended as straight forward as possible, and with face to one side so that the nose and mouth are free for breathing. If possible, avoid so laying the body that any burned places are pressed upon; and do not permit bystanders to crowd around and shut off fresh air.

Kneel straddling the subject's thighs and facing his head; rest the palms of the hands on his loins, that is, the muscles in the small of his back, and have the thumbs nearly touching each other, with the fingers spread over the lowest ribs as shown in the illustration.

With the arms held straight, swing slowly forward so that the weight of the body is gradually brought to bear upon his back as shown in Fig. 454. This operation, which should take from two to three seconds, must not be violent, else the internal organs may be injured. It tends to compress the lower part of the chest and the abdomen, and drive out air from the lungs.

Now immediately swing backward so as to remove the pressure, but leave the hands in place, thus returning to the position in Fig. 453. This relieves the pressure, allowing the lungs to expand through their elasticity and take in air. After two seconds, swing forward again, and repeat the double movement of compression and release twelve to fifteen times a minute,—a complete respiration in four or five seconds.

1382. If a watch or clock is not at hand, what is a safe way to time the backward and forward movements of the body?

Follow the natural rate of your own deep breathing,—

Fig. 454.—Treatment for Electrical Shock: Expiration—Pressure On.

swinging forward with each respiration, and backward with each inspiration. While this is being done, an assistant should loosen any tight clothing about the subject's neck, chest or waist.

1383. How long a time should the periodic movements be continued?

The backward and forward movement should be continued, if necessary, two hours or longer, without interruption, until natural breathing is restored or until a physician arrives. Even after natural breathing begins, carefully watch that it continues. If it stops, start the movement again. During the period of operation, an assistant should keep

the subject warm by applying a covering or laying beside his body bottles or rubber bags filled with warm water.

1384. Would stimulants help in reviving the victim?

It is not advisable to give any liquids whatever by mouth until the subject is fully conscious, as this would temporarily interfere with his breathing.

1385. How should burns on the body, caused by electricity, be treated?

The raw or blistered surface should be protected from the air. If clothing sticks to it, do not peel it off—cut around it. The adherent cloth, or a dressing of cotton or other soft material applied to the burned surface, should be saturated with picric acid (0.5 per cent.). If this is not at hand, a solution of baking soda (one teaspoonful to a pint of water) may be used, or the wound may be coated with a paste of flour and water. Or it may be protected with a heavy oil, such as machine oil, transformer oil, vaseline, linseed, carron or olive oil. Cover the dressing with cotton, gauze, lint, clean waste, clean handkerchief or other soft cloth, held tightly in place by a bandage. The same coverings should be lightly bandaged over a dry, charred burn, but without wetting the burned part or applying oil to it. Blisters should not be opened.

1386. Who is responsible for the supervision and control of an electrical station?

The superintendent or manager

1387. What qualifications must a station employee possess in order to succeed as the superintendent or manager?

He must have an intimate knowledge of local conditions and requirements, have practical experience in the running of generators, motors, transformers, etc., and understand their principles of operation. He should be keen of perception, so that on his regular tours of inspection about the plant he will be sure to locate wear or irregular operation of the station equipment. The monotony of continual contact with

his surroundings tends to render the station attendant oblivious to these matters, which should therefore be carefully watched by the superintendent. He must also possess executive and business ability and have strict integrity.

1388. What is one of the first problems that often confronts the new superintendent?

He is frequently given an electrical station equipped with old apparatus and machinery and is confronted with the problem of increasing the net earnings without making any radical changes in the equipment.

1389. How can the superintendent best solve the problem mentioned in Answer 1388?

Inasmuch as thousands of dollars have probably been invested in the installation, it is usually impracticable to scrap the old apparatus and machinery at the start and purchase an entirely new equipment. The new superintendent should therefore be content temporarily with the existing apparatus, but he should investigate the situation thoroughly so that when money is available he will be able to make the most necessary additions and improvements to the plant.

1390. What principle should serve as a guide in making additions and improvements?

Make the station conform to modern practice so as to reduce as much as possible the cost of current production. In this connection it is well to bear in mind that boilers, engines, generators and similar equipment cannot usually be purchased at bargain prices and turn out satisfactorily. The kind of workmanship and the quality of the materials that must necessarily be used in a generator, for example, to produce good permanent results, are of such a standard as to force the price above that ordinarily asked for most any other machine of a similar weight and size. Generators and motors at bargain-counter prices are the most expensive ones in the end, and it behooves the purchaser to deal only with reputable concerns which have the welfare of their customers at heart.

1391. **Give an approximate idea of the cost of modern power plant equipment.**

Equipment	Cost Installed
Boilers, fire tube	$11 per B. H. P.
Boilers, water tube	$14 per B. H. P.
Engines, simple, high speed	$13 per I. H. P.
Engines, compound, medium speed	$19 per I. H. P.
Generators, direct connected	$15 per kilowatt
Switchboards	$7 per kilowatt

1392. **How should the recommendations for changes and improvements in a power plant be put before the directors?**

They should be formed into a clear statement, covering the best kind of apparatus to install, the cost and the probable profit resulting through its installation.

1393. **If the suggestions are approved, and, when put into effect, result in an increase of business, what should be the next move?**

The money resulting from the increased business should be applied to further alterations and extensions of the plant. Gradually, the transformation of the station will thus be brought about, and when satisfactory conditions are once secured, every effort should be made toward their maintenance.

1394. **What are the best methods of obtaining good men and retaining their services?**

Showing appreciation of their work by paying them what they are worth and advancing them to higher positions when vacancies occur or new situations open up.

1395. **How should the superintendent be governed in issuing orders to his subordinates?**

The orders must be worded plainly and should be of such a nature that they may be enforced to the letter. Under no conditions must favoritism be shown, and social or political influence should not be considered in the proper enforcement of the orders and regulations of the station.

1396. What amount of technical training should a man have in order to become a competent station superintendent?

He should preferably have three or four years' study and experimental work in electrical engineering at a technical school. If he has a persistent, studious nature and is naturally inclined toward the subject, he may obtain the theoretical training by home study.

1397. What amount of practical training should a man have to become a competent station superintendent?

The technical training should be supplemented with several years' practical training. A number of our large electrical manufacturing concerns have regular channels through which one possessing a technical education and being fortunate enough to enter, can secure much valuable experience in the design, construction, testing and operation of the various classes of electrical machines.

1398. How is the actual worth of a station superintendent to his company usually judged?

From a profit-making basis.

1399. Give some general rules for increasing the net profits.

Reduce the operation and maintenance expenses to a minimum. After figuring the former on a kilowatt-hour basis, compare them with corresponding expenses in similar stations, and determine in which direction efforts should be made toward reduction. To reduce the cost of maintenance, have frequent inspections made of all machines and appliances, and whenever a defect is first noted have it attended to at once.

1400. What privileges should be given the station superintendent by his employers?

Inasmuch as the superintendent is held directly responsible for the results, he should be given the privilege of putting into effect whatever methods he deems advisable. His methods

should not be disputed or confidence lost in his ability until positive proof of failure is at hand. In the meanwhile his employers should endow him with full power so that his subordinates will regard him as the one man in authority whose orders are not to be questioned.

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